

CHAPTER 1

INTRODUCTION

Following Schumpeter's (1939) exposition of the importance of understanding the coevolution of technology, firm and industry structure, evolutionary economists have taken on this dynamics to view economic growth as a differentiating, non-linear and complex process (Nelson, 2008). Taken together, any attempt to understand firms' successful transformation from technological followers to leaders requires a profound unravelling of the sectoral innovation system associated with technological leaps. Economic growth, thus, is not an aggregate phenomenon; rather, it is determined by the country's different sectors, each characterized by its own dynamics (Nelson & Winter 1982; Nelson 2008).

The integrated circuit (IC) industry has undergone major structural changes since its infancy in the 1950s, which is largely attributed to changes in firms' business models and technologies. The industry began life dominated by large-scale vertically integrated companies, referred to as the 'integrated device manufacturers' (IDMs) in the United States. Born in the Bell Laboratory, ICs were first commercially produced by Fairchild. Subsequently, multinational corporations (MNCs) like Fairchild, Intel, International Business Machines (IBM), National Semiconductor and Advanced Micro Devices (AMD) internationalized their operations to East Asia since the 1960s. Since the emergence of the world's first pure-play foundry in Taiwan in 1987, the industry experienced a change of manufacturing landscape as firms began to vertically disintegrate to specialize in specific scopes. Since 2005, the IC industry experienced increasing stability of innovators and increasing concentration of innovations.

A pure-play foundry is a ‘dedicated’ chip-fabrication service provider which fabricates wafers for other IC firms without its own brand name. By introducing the innovative business model, Taiwanese firms pioneered the disintegration activities to set into motion horizontal specialization in the IC industry. Veblen (1915) and Gerschenkron (1952) pioneered the notion of latecomer effect. In addition, according to Gerschenkron (1952), the more backward a country is, the shorter period it requires to catch up with the forerunners. The extant literature on the catch-up experience of Korean and Taiwanese firms with those in the more technologically advanced nations have focused on the advantages latecomers enjoy in reaching the technology frontier (Amsden, 1989; Mathews & Cho, 2000; Lee & Lim, 2001).

The remarkable story of Taiwan Semiconductor Manufacturing Company (TSMC) started when its architect, Morris Chang, helmed the administration of the Hsinchu Science Industrial park to fashion the launching of the firm in 1987 as a joint venture (JV) with Phillips. In the space of 25 years from its establishment in 1987, TSMC had become the largest pure-play foundry company in the world, enjoying in 2011 an annual revenue advantage of more than USD10 billion over the world’s number two pure-play fabrication foundry, i.e. United Microelectronics Corporation (UMC) (Gartner, 2012).

Other latecomer countries in Southeast Asia such as Malaysia are trying to grow through technological upgrading. The Malaysian government realized its role to foster a knowledge-based nation by upgrading the country’s human capital (NEAC, 2010). To create such a supportive environment, the government has set up a number of meso-organizations, including public research institutes, such as, the Malaysian Institute of Microelectronic Systems (MIMOS) in 1985 to mimic the catch-up route of Taiwan. Unfortunately this remains as a vision unrealized due to the severe lack of the right strategies to manage and transfer technologies (Rasiah, 2010).

This study begins with a macro-level analysis by examining the evolutionary processes that have defined the IC industry through the lens of changing technological regimes. The study goes on to examine latecomer resource acquisition strategies through industrial structural change to catch up and leapfrog incumbents. Lastly, the study attempts to advance existing understanding by a micro-level analysis to explore why certain latecomer firms forge ahead to eventually become industry leaders while others remain at the catch-up or keep-up stages.

1.1 Statement of Problem

Despite starting as a contract manufacturer since 1987, the pursuit to reach the technology frontier has driven Taiwanese IC firms to target scale- and knowledge-intensive research and development (R&D) activities. However, while the IC industry has undergone major structural changes, research focusing on this transformation process has remained scanty. While there are a number of works that examine particular industries to identify Schumpeterian cycles of innovation, few have actually attempted to discuss the industry's changing technological regimes. Consequently, the mechanisms behind the industry's transitional process after the emergence of the first pure-play foundry have remained vague.

Also, existing research have lucidly discussed how several latecomer firms have caught up technologically in many industries by stressing the role of institutions (Amsden, 1989; Mathews & Cho, 2000). However, several questions have remained unaddressed as latecomer countries like Malaysia tried to mimic the Taiwan catch-up model by spinning off pure-play foundries but failed. This indicates that the success or failure of a latecomer's catch-up also depends very much on firms' resource acquisition strategies and how they link with the complex mechanisms evolving in the industry, including

choices of organizational boundary, industrial structural changes and changing value systems. This thesis seeks to address this gap.

While existing studies have provided useful examples of how latecomer firms have caught up technologically in many industries, they do not help much in addressing the popular questions of: ‘Why do firms differ and how does it matter?’ (Nelson, 1991). More often than not, the question of why firms’ performances diverge through time despite a similar start-up and catch-up model has been overlooked. This area of study can generate significant strategic and managerial implications as it demarcates the boundary between becoming an industry leader and becoming just a latecomer firm that has successfully caught up.

1.2 Research Aim

The development of the Taiwan IC industry has been a crucial factor in the successful transformation of the nation into a high income country. However, the story of the Taiwan IC industry has not been easily replicated elsewhere. In fact, several latecomer countries like Malaysia have not been able to even come close, despite after years of attempting to mimic the Taiwan catch-up model.

In light of the remarkable catch-up experience of Taiwan in the IC industry, it is significant to extend the existing scope of studies. This includes the understanding of how the technological environment of a specific industry is changing in time; latecomer resource acquisition strategies, as well as, how certain latecomer firms could successfully be transformed to become an industry and technology leader.

Extending these research areas could have important policy and managerial implications to other latecomer countries or firms who are seeking ways to catch up. Latecomers must consciously make strategic choices to upgrade their capabilities with the potential

for extending beyond the firm to the national level. Because it is necessary to learn from Taiwanese IC catch-up strategies, the problems identified above shall not be ignored.

1.3 Research Questions

Three research questions are identified in this study. Technological regime has always been used as a useful conceptual tool to examine the technological environments of innovating firms. To explain the transitional process of firms between different technological regimes, firms' choices of organizational boundaries shall not be ignored especially when the industry experienced vertical disintegration process due to the emergence of the latecomer's contract-manufacturing model. The first research question is, how does a high-tech manufacturing industry transit between different technological regimes and can the industry's technological regime be endogenous to firms? This question requires the mapping of the technological differences between the industry's downstream and upstream firms, how firms' choices of vertical boundaries are impacted, the resulting industry patterns of innovation, and how a technological regime eventually becomes endogenous. The answer to this research question has important implications for the subsequent analysis in this study. It is important to establish the importance of changing technological regimes, as it provides the fundamental pillar to understand and analyze innovative activities in a high-tech manufacturing industry.

The second research question seeks to examine how, in particular institutional support and start-up strategies, structural changes of a high-tech manufacturing industry affect latecomer catch-up processes. To examine this question, the study incorporates the mechanisms of changing value systems and resource acquisition strategies into the analysis. Since strategies embodied in business models can collectively cause changes to industrial structures, it is also important to include a study of specialization in different production stages.

The third research question seeks to identify the underlying causes of diverging achievements over time of firms with similar start-up experience. Specifically, “What are the entrepreneurial roles and strategies deployed by firms in turning a latecomer firm into an industry leader in a high-tech manufacturing industry?” To answer this question, the study seeks to find out how the progress of a high-tech manufacturing industry is endogenous to firms and what lies at the heart of the generative process that leads to such progress? To answer this question, the analysis incorporates organization-level theories, including organizational path dependence, coevolutionary lock-in between firms and industry, as well as, firm-level absorptive capacity.

1.4 Research Objectives

The research questions identified in this study are targeted at achieving the following objectives. Firstly, the study seeks to find out how the technological regime of a high-tech manufacturing industry evolves through time and leads to different innovation patterns. In doing so, it seeks to examine the endogenous transition process of technological regimes, including how specific technological aspects affect firm choices of organizational and network boundaries, as well as how innovation patterns evolve in the process.

Secondly, the study seeks to examine how can a latecomer firm in a high-tech manufacturing industry catch up and leapfrog incumbents as the industry experiences structural changes and different value systems, by analysing the resource acquisition process of successful and unsuccessful firms. In addition, the study seeks to examine differences in strategies of latecomer firms at different manufacturing stages across the value chain.

Thirdly, the research seeks to find out how can a latecomer firm in a high-tech manufacturing industry become a leader in terms of technology and economic

performance, by examining firm strategies for organizational path dependence and inter-path dependence with the industry. These three research questions are targeted at providing important contributions to organizational theories and strategies for high-tech manufacturing industries, especially the IC industry.

1.5 Theoretical Considerations

Since the emergence of the fabless-ecosystem and the foundry-ecosystem in the late 1970s and mid 1980s respectively, the landscape of the IC industry has changed significantly, characterized by the vertical disintegration of firms across the value chain. The second most important change in the IC industry landscape began in the mid 2000s, of which vertical integration (at least partial) or concentration of innovations was observed. It is important to examine the mechanisms behind the changes experienced by the firms in the industry. The study begins by reviewing some of the useful theories to explain this phenomenon; they are (1) technological regimes, (2) driving forces of organizational choices, (3) industry's innovation patterns, and (4) organizational feedback on technological regimes. The first research proposition examined is that transitions in technological regimes provide different environments at different points in time for latecomers to catch up and to leapfrog incumbents.

The literature on latecomer effect also discusses the advantages sought by latecomers through the application of different strategies. The extant literature also examines how global value chains (GVCs) work as windows of opportunity for latecomers to catch up. The strategic choices of latecomers include linkages, leveraging and learning, while there is a set of criteria latecomers use to target the types of external resources to gain, which include rareness, imitability and transferability (Mathews, 2002, 2006). In addition, the study also reviews the critical concepts of firm-level core competency, i.e. Penrose's (1959) resource-based view, in an open innovation context where industrial

structural change takes place. The review also takes the cue that the concept of organizational core-competency is less prominent in open innovation systems when the industry experiences structural change.

Finally, the literature review targets studies on organizational routines, followed by discussion of key concepts in theorizing process the mechanism of path dependence. The role of organizational absorptive capacity is helpful in determining an organization's trajectory. The model of organizational path dependence put forward by Sydow et al. (2009) is particularly important. The possibilities of path breaking or path creation are explored by incorporating the role of 'vision' mustered by actors (entrepreneurial management). Of importance here is the concept of mutual reinforcement between an organization and its industry, which can lead to coevolutionary lock-ins. The research seeks to examine the following research proposition: actors can lead firms to escape from organizational path dependence through coevolutionary lock-ins. In doing so, the study examines the factors lie at the heart of the generative process to generate managerial implications. Figure 1.1 presents the theoretical framework of the thesis.

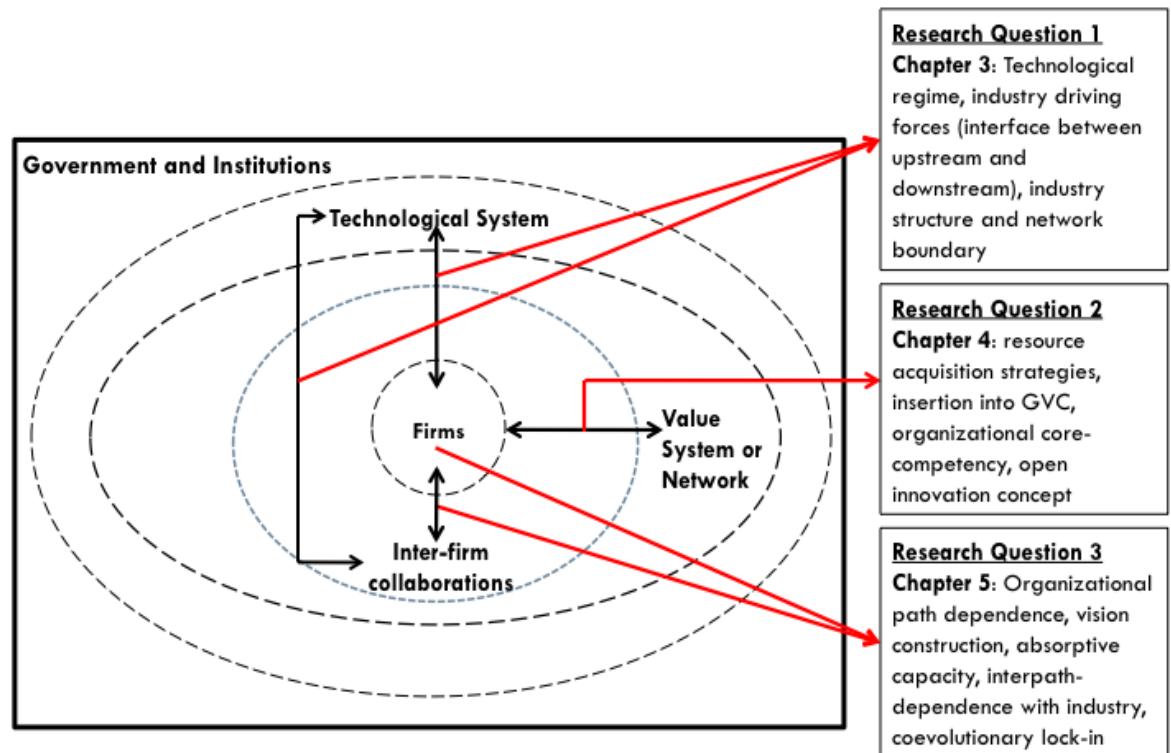


Figure 1.1: Theoretical Framework

Source: Authors.

1.6 Methodological Considerations

This research adopts both qualitative and quantitative methods. In line with the Fundamental Principle of Mixed Research, words, narratives and images add meanings to numbers while numbers add precision. On the one hand, open-ended questions were used and insights were sought through in-depth interviews with top management. It seeks to emphasize defined boundaries of categorizations to avoid diverging perceptions among interviewees. On the other hand, quantitative data was sourced from reliable data providers to corroborate and justify findings from the interviews. Secondary data was obtained from reliable documentation and databases such as IC Insights, CLSA Research and Gartner.

Nevertheless, the predominant research method adopted in this study is qualitative, which is widely used in ethnography (Buchanan, 1995). It relies on purposive rather than probabilistic research and seeks to intuitively and theoretically identify the key subjects, organizations and enterprises, and a network of agents to capture in-depth the dynamics of a phenomenon. As is well known, this analytical approach forsakes generalizability but allows a more holistic understanding of phenomena of the kind described above. For this study, it suffices to study the propositions by identifying the key actors involved. The identification of key actors will help facilitate the mapping of the subjects studied.

The case study approach is adopted in order to provide analytical depth and to handle crucial but non-quantifiable factors, e.g. corporate decision-making, leaderships and constraints. In addition, the approach enhances the understanding of complex issues such as the role of entrepreneurial management in formulating strategies. The main units of analysis are the latecomer IC firms, although the thesis also examines some non-firm institutions with links to the firms, such as, public research institutes.

The reasons for selecting Taiwan as the country of study are obvious. Not only that Taiwan has successfully caught-up economically, firms in the country have also arrived at the technology frontier in the IC industry through different strategies whereas Malaysia is a latecomer country still struggling to catch-up. As for the firm-level selection, the case-study approach is critical to provide opportunities for emphasizing practical lessons as other latecomers may learn from the successful examples, such as, TSMC. The Malaysian firms are used as shadow cases to improve generalizability.

Major emphasis is placed on IC firms that undertake wafer-fabrication activities in this research. This is because a knowledge economy is embedded in the knowledge engine of particular economic activities. Wafer fabrication is the ‘learning centre’ - the main

source of new productive knowledge in IC manufacturing. Technological innovation is driven by demands for practical solutions in productive, especially the manufacturing, sector. In contrast, knowledge-intensive services, such as, IC design or fabless firms can only be developed after a country first acquires the ability to fabricate the relevant products, thus the prosperity of services firms depends on the manufacturing firms.

The overall timeframe of this study covers the period 1970 – 2013. However, each analytical chapter sets different timeframes to achieve specific research objectives. Taiwan began to formulate strategies to catch up in the IC industry from 1974 when the Industrial Technology Research Institute (ITRI) was started (Mathews & Cho, 2000). Whereas the first spin-off from ITRI began life as an IDM and transformed its business model in the mid of 1990s, the world's first pure-play foundry was started in 1987. The 1990s is the period when Taiwanese foundries began to grow to become industry leaders, as well as, the period when Malaysian foundries began to enter the industry as latecomers. Strong emphasis is given to the period after 2000 – the period when the pure-play foundries began to consolidate their operations.

1.7 Thesis Outline

The thesis is organized as follows. Chapter 2 presents the literature review where the relevant theories are reviewed and the theoretical considerations for the research are discussed. The three identified research questions are examined separately with three different analytical frameworks in Chapter 3, 4 and 5. Some of the research propositions use specific research methodologies and they are discussed in the respective chapters. Chapter 6 concludes with the synthesis of the study, implications for theory, strategic management and policy, as well as, limitations.

CHAPTER 2

LITERATURE REVIEW

The first section of this chapter reviews the theories that explain changing technological regimes experienced by the IC industry; they are (1) technological regime and its relevant dimensions, (2) driving forces of organizational choices of vertical boundaries, (3) industry's innovation patterns, and (4) organizational feedback to technological regimes. To answer the second research question, the second section reviews studies on latecomer technological catch-up, latecomer insertion into GVC, resource acquisition strategies, and how open innovation affects value systems. The third section discusses organizational studies associated with routines, path dependence, absorptive capacity, vision construction, and coevolutionary mechanisms between firms and industry.

2.1 Technological Regimes and Industry Patterns of Innovations

A technological regime can be understood as the nature of technology representing a particular knowledge environment that enables firms to conduct problem-solving activities (Nelson & Winter, 1982; Winter, 1984, p.289) or the list of attributes that mould the development of physical technologies in a particular industry (Nelson, 2008). The process of technological learning is industry specific because different nature of technologies involves different uniqueness, tacitness and complexity (Winter, 1987). A similar notion of a technological regime was referred to by *Teece (1996, p. 194)* as constituting a set of 'fundamental characteristics of technological development'.

2.1.1 Technological Regime and its Relevant Dimensions

Technological opportunities and appropriability bring important impacts on an industry's innovation pattern. Empirical research by Gort and Klepper (1982), Cohen and Levin (1989), and Audretsch (1995) show that the factors determining the dynamics

of market structure and innovation go far beyond firm size or demand and are very much affected by aspects like opportunity and appropriability.

The extant literature identified six key characteristics, namely uncertainty, path dependence, cumulateness, irreversibilities, technological interrelatedness, tacitness and inappropriability (Teece, 1996). A technological regime is also defined by a particular combination of different technological dimensions, including the four prevailing ones identified by Breschi et al. (2000) – technological opportunities, appropriability of innovations, technical cumulateness and the properties of knowledge base.

To explain specifically the fabless eco-system, Yoon and Malerba (2010) developed a history-friendly model to show that technological interrelatedness, knowledge generalizability, economies of scale, and distance threshold of consumption cause changes to the vertical and horizontal boundaries of firms. Those changes happen in path-dependent ways. The following dimensions that form an industry's technological regime are considered; they are critical in understanding technological progress of the IC industry.

2.1.1.1 Technological Interrelatedness

Technological interrelatedness between subsystems has a bearing on organizational choice of innovations and boundaries (Teece, 1996; Yoon & Malerba, 2010). In the fabless eco-system, decreasing interrelatedness in production stages has played an important role in the disintegration of design from manufacturing. Park et al. (2008) has examined in detail how technology relatedness, i.e. similarity of production process technology and technology innovation systems between two different business divisions, contribute to Samsung's success in diversifying into TFT-LCD business.

2.1.1.2 Cumulativeness

The cumulative nature of technical advance in particular the knowledge regime helps transform present innovative activities into the technological innovation of the future. Any given innovation paves the way for a multitude of streams for further improvements to the original one, or spirals into new areas of innovation inspired by the original one. High levels of cumulativeness are therefore most apparent under environments where technological continuities and increasing returns underpin the nature of the industry (Breschi et al., 2000, p.392). The IC industry is characterized by such a condition, specifically Moore's Law, which states that transistor density in ICs doubles while the minimum line-width halves approximately every two years (Dubash, 2005). Whereas the pace of node miniaturization has remained in logic chips, it has quickened to 12 months in memory chips (Rasiah et al., 2012). A firm's development at a technology node acts as a guide for the firm's future development of subsequent nodes.

Under a specific regime, technological development progresses cumulatively along a path underpinned by that regime. Because technological progress builds on previous accomplishments, which are tacit and proprietary, technical development is therefore contingent on organization-specific characteristics (Teece, 1996). Hence, organizational technological development and capability building can be very much confined to previous achievements.

2.1.1.3 Path-dependency

There is a certain path of capability building, which organizations would follow at any given point in time. That path defines the set of strategies available to the organization; it also constrains the organization's future internal repertoire (Castaldi & Dosi, 2006). Following the theory of technological path dependence, a firm's technological knowledge base does not deviate too far away or too quickly from its preceding

direction because the firm's technical change follows along stable trajectories (Dosi, 1982; Pavitt, 1986; Patel & Pavitt, 1997).

The notion of path-dependency recognizes that 'history matters' and within the studies of evolutionary economics as put forward by Nelson and Winter, the concept helps explain why technological change is mostly regular and its development is bounded (Nelson & Winter, 1977). Thus, a firm's previous investment decisions and its repertoire of routines determine and set bounds around its behaviour in the future (Teece, 1988). Some researchers have studied the levels of 'historicity' in explaining how path dependence can range from mere dependence on origins to strong dependence on a specific series of events (David, 2001; Bassanini & Dosi, 2001; Castaldi & Dosi, 2006). New product and process developments of a firm often lie within the technological neighbourhood of previous developments.

2.1.1.4 Degrees of Economies of Scale

Degree of economies of scale also plays an important role in determining organizational boundaries in the IC industry. The capability gap among wafer fabs widens when the importance of economies of scale increases, which suggests that IDMs with low capability tend to outsource more to these independent fab owners. Malerba et al. (2008) noted that the comparative technological capability of upstream firms over downstream firms is an important factor in the organizational choice of vertical disintegration. It is reasonable for fabless firms to increase their outsourcing to foundries that have stronger manufacturing capabilities than them. In the IC industry, the capabilities concerned are fabrication capabilities to achieve high productivity, i.e. the yield rate.

2.1.1.5 Technological Opportunities

Technological opportunities denote the likelihood of technological innovation for any given amount of research investment (see Breschi et al., 2000, p.395). High opportunities indicate that firms are easily motivated to undertake innovative activities as there are meaningful incentives and not much scarcity in the economic environment (Breschi et al., 2000). Therefore, high opportunities also mean that the majority of the newly developed technological innovations in the industry are impactful.

2.1.1.6 Technological Appropriability

Appropriability of innovations denotes the possibility of preventing innovations from being imitated and of benefiting, i.e. reaping profits, from innovations. An industry with high technological appropriability is one where technological innovations are easily protected from imitation. Low appropriability means that the economic environment of the industry is challenged with high level of externalities (Levin et al., 1987). Therefore the high appropriability condition provides incentives for firms to allocate resources for R&D.¹

2.1.2 Organizational Boundaries

Formal structures of firms and their external linkages are vital determinants of organizational capability building (Teece, 1996). There has been research to find out the factors and driving forces of organizational choices, including diversification into conglomerate firms (Kim & Lee, 2003). Through the use of a history-friendly model, Yoon and Malerba (2010) found that the entry of new downstream firms (fabless firms) can strengthen the capability of pure-play foundries. Therefore, the conditions of entry into the fabless market are able to determine the average vertical boundary of the

¹ Technological appropriability condition affects the outputs of innovation in two ways, i.e. an incentive effect and an efficiency effect (Levin & Reiss, 1988).

industry. The feedback loop takes place when increasing demand for outsourcing enhances the capabilities of foundries which in return induces higher entry of fabless firms.

2.1.2.1 Vertical Boundaries (Vertical Integration or Disintegration)

Some examples depicting how vertical structures of organizations are linked to the rate and direction of innovations include Frankel's (1955) argument that the slow diffusion of innovations in the British textile, iron and steel industries around the turn of the century was attributed to the absence of vertically integrated firms.

Vertical integration allows room for complementary investments among firms through the sharing of investments (Richardson, 1990; Williamson, 1975). The drivers of organizational integration to expand firms' scope of activities have been studied in detail (Teece, 1980, 1984, 1986). More often than not, firms choose to integrate or to diversify as a result of proprietary and technology transfer issues, provided that there are no existing well-established incumbents in their downstream activities and that downstream integration will not result in generating excess capacity (Teece, 1996). Therefore, vertical integration and product diversification are effective responses to contractual, proprietary and technology transfer problems in certain technological environment. The expansion of organizational boundaries can also come in other mixed mode forms, including JVs and different profit-sharing collaborations under different conditions of the above stated criteria (Teece, 1996).

2.1.2.2 Virtual Vertical Integration

The concept of virtual vertical integration is relatively new in existing studies. Nevertheless, the phenomenon is gaining prominence in the IC industry. Few studies have explored this important concept. Among them are Kodama (2011) who, in his

efforts to examine how interactive business communities accelerate firm innovations through network boundaries, points to the role of value chain integration in TSMC's business model. Collaboration in the context of value chain integration means moving from a traditional segregated model to an integrated model (Kodama, 2011, p. 117). Virtual vertical integration is also referred to as a cluster, where firms from different specialization gather to collaborate and innovate (Lu, 2005). It is described as heterogeneous integration for system chips as the cluster combines firms specialized in chip design, application and subsystem design, wafer fabrication, and packaging and testing.

2.1.2.3 External Linkages

Analyzing the combined dynamics between the networks of collaborations and technology is complex. Networks of collaborations are dependent on the organizational choices and the industry's technological environments. A network is able to impact on technological change, firms' growth or even the competitive structure and that these changes can be self-reinforcing (Malerba, 2007).

While establishing new boundaries within large MNCs, increasing inter-firm collaborations and open networked innovations have also led to blurred boundaries between firms (Cantwell, 2013). Networking and strategic alliances provide room for negotiations instead of authority and the opportunities for expanding organizational boundaries as the networked firms appropriate synergies from integration while avoiding significant costs. These collaborative arrangements come in various modes, including technology licensing, R&D JVs and consortia, manufacturing JVs and co-marketing arrangements (Teece, 1996).

Another interesting question to answer is how the dynamics of networks or external linkages are linked to technological discontinuities. Networks can have important

impacts on the technological environment of an industry, especially when networks that are created after certain technological discontinuities can consolidate within the stabilization of technology and large incumbent firms increase their dominance in the network structure (Madhavan et al., 1998; Malerba, 2007).

2.1.3 Industry's Patterns of Innovations

Schumpeter Mark I and Schumpeter Mark II industries differ in the ways innovative activities are structured and organized.² “Creative destruction” under Schumpeter Mark I is characterized by low barriers of entry into technological activities and a significant role played by new small firms and entrepreneurs in innovations. New firms and entrepreneurs challenge the incumbent firms and constantly disrupt the existing ways of manufacturing, organization and distribution, hence diminishing the quasi-rents attributed to earlier innovations. Schumpeter Mark II is characterised by ‘creative accumulation’ where the dominance of large resourceful firms and barriers to entry prevent the birth of new innovators. These barriers consist of the accumulated stock of technological knowledge, R&D competencies, production, distribution and financial resources of established firms. The latter distinguishes firms with strong internalized R&D activities targeted at searching new stocks of knowledge.

The Schumpeterian Mark I and Mark II patterns of innovation have also been characterized as ‘widening’ and ‘deepening’ respectively. A widening pattern of innovative activities is associated with continuously expanding the innovative base through the entry of new innovators and the progressive loss of competitiveness and technological dominance of established firms. A deepening pattern of innovation occurs with the concentration of a few innovators. These firms innovate from time to time

² The terms Schumpeter Mark I and Schumpeter Mark II were introduced by Nelson and Winter (1982) and Kamien and Schwartz (1982) to explain the different dynamics of innovative activities explained by Schumpeter (1934) and Schumpeter (1942).

through the constant accumulation of technological capabilities (Malerba & Orsenigo, 1994; 1996).

Specifically, three dimensions of Schumpeterian patterns of innovation can be identified as attributed to the technological regime, i.e. the rate of concentration of innovative activities among firms, the degree of stability in the hierarchy of innovative firms, and technological entry and exit of the industry (Breschi et al., 2000). A Schumpeter Mark I industry is characterized by a large set of highly turbulent innovating firms, of which there are high technological opportunities, low appropriability and low cumulativeness within firms and a limited role of generic knowledge. These conditions result in low concentration of innovative activities, a relatively large number of innovators, high rates of technological entry and high instability in the hierarchy of innovators (Breschi et al., 2000, p.395). Whereas a Schumpeterian Mark II industry is characterized by low opportunities, high appropriability and cumulativeness at the firm level with a strong internalized tacit and explicit knowledge base, which cause a high degree of concentration of innovative activities, low rates of entry and remarkable stability in the hierarchy of innovators (Breschi et al., 2000, p.395).

Kamien and Schwartz (1982), through their 'market structure and innovation' approach, dealt with the relationship between firm size and its rate of innovation on the one hand and monopoly power on the other. However, the approach did not recognise the mutual causation between innovation, market structure and firm size. Dasgupta and Stiglitz (1980) and Nelson and Winter (1982) argued that these variables are endogenously co-determined. Nevertheless, such relationships of mutual causation and co-determination of factors that shape the structure and innovation patterns of the industry have remained rather unexplored.

2.2 Technological Studies on Latecomers' Catch-Up

Veblen (1915) and Gerschenkron (1952, 1962) pioneered the notion of latecomer effect. Latecomers are regarded as countries or firms that arrive relatively late in certain industries with a clear target, which is to increase their real incomes by closing the gap they have with the advanced forerunners (Mathews, 2006: p.314). Latecomers can define a catch-up roadmap for themselves to capture the access of forerunners' knowledge and technology. In general, catching-up is analogous to the relative speed of runners racing on a path set by forerunners, while technology building is akin to the piling of bricks with an undefined vertical goal (Perez, 1988: p.86).

The critical mechanism lies in the role of institutions and institutional change to overcome latecomer disadvantages and to benefit from latecomer advantages. The status of late arrival allows firms to strategize and access existing advanced technologies, and hence, exempts them from repeating the whole technological path advanced by the forerunners (Veblen, 1915; Gerschenkron 1952; Abramovitz, 1956; Mathews, 2006). To further exploit latecomer advantages, firms can hasten their catch-up process by breaking the organizational inertia faced by incumbents through strategic alliances and state support (Mathews, 2006). Because latecomers strategize around the possibilities inherent in their latecomer status, it is important to examine specifically the firm-level strategies deployed by different latecomer firms in order to identify the differences that distinguish successful catch-ups from the unsuccessful ones.

2.2.1 Latecomer Catch-Up Strategies

Gerschenkron's (1952, 1962) ideas stand diametrically opposed to Rostow's (1960) notion of 'stages of growth', where development is perceived as following a series of linear and orderly steps in a sequence that cannot be changed. This "stage" concept obviously denies any possibility of catch-up and hence renders unnecessary any strategy

orchestrated to achieve this catch-up. Another example of a linear one-directional development model is Akamatsu's (1962) "Flying Geese" model, which was proposed to explain the rise of East Asian economies as a sequential process. Gerschenkron argues, on the other hand, that the building of new institutions and the pursuit of new strategies under the right circumstances that are supported by strong development policies can facilitate economic catch-up.³

Korea and Taiwan are two major Asia examples of how technological catch-up can help move countries from low-income to high-income status. Considering the case of Korea for which the government has pursued the Schumpeter Mark II model (creative accumulation), the country is characterized by a concentrated industrial structure and large conglomeration of firms since 1970s to focus on the growth of automobiles, semiconductors and telecommunications (Malerba & Nelson, 2012). To protect the successful *chaebol* - i.e. diversified business groups whose size and diversity are similar to those of Japan's *keiretsu* - from skyrocketing oil price in 1973-1975, South Korea's government provided strong insulation to these large firms through the maintenance of stable exchange rates, highly subsidized loans and a protected domestic market despite having to borrow extensively from abroad (Rasiah, 2011: p.167). The government also strategically used performance standards as strong institutions to support technological catch up in certain industries. Successful examples of this approach are Samsung, Hyundai and Pohang Steel Company (POSCO) in electronics, shipbuilding and automobiles and steel respectively (Amsden, 1989; Kim, 1997).

During the technological catch-up process of firms in Taiwan, the national government applied a framework consistent with the sectoral system of innovations (SSI) approach

³ In the search for what explains technological advance, institutions are referred to as the rules of the game (North, 1990). Evolutionary economists often refer to them as whatever that shapes the behavioral patterns of actors in societies (Rasiah, 2011). The role of universities, government labs and professional societies are examples of critical institutions (Nelson & Winter, 1982).

by following initially the Schumpeter Mark I model (creative destruction) to support entry of new small firms into the industries like ICT, thereby stimulating the birth of numerous small and medium size firms, as well as, high industrial turbulence (Malerba & Nelson, 2012). The success of Taiwan's indigenous IC firms is also attributable to selective interventions by the government, through the creation of ITRI (Mathews & Cho, 2000). The government focused on the development of its vertically decentralized structure, in which firms were specialized in particular manufacturing stages (Rasiah & Lin, 2005).

Consistent with the arguments of the evolutionary economists (Veblen, 1915; Nelson, 2008), latecomers always evolve through the new conditions to effect the catch-up process. In the IC industry, as Rasiah (1988), Mathews (1997) and Brown and Linden (2009) have noted, crises have offered tremendous opportunity for latecomers to leapfrog ailing incumbents. The economic shakeout that accompanied the 1979-1980, and 1985-86 cases saw Samsung acquiring a number of American IC firms that helped it to leap ahead to create more advanced memory technologies (Edquist & Jacobssen, 1987; Rasiah, 1988). Founded in 1980, UMC benefited from the technology acquisition from the financially troubled RCA by Electronics Research and Service Organization (ERSO) in Taiwan in 1976 (Rasiah & Lin, 2005). Morris Chang subsequently engineered the founding of TSMC between government capital and Philips in 1987 as the latter began to rationalize its losses in the semiconductor division. Hence, it is important to examine the catch-up process of past latecomers, and then seek to draw implications for new latecomers. Gerschenkron's idea, which he applied to countries can be extended to firms at which level strategies are drawn up and issues are dealt with (Mathews, 2002, 2006). Like countries, latecomer firms have accumulated knowledge on which to learn and draw up plans to achieve their catch-up objectives.

2.2.2 Global Value Chains

Insertion into global value chains (GVCs) has helped latecomers to connect with global buyer and supplier activities around the world, without necessarily being controlled by MNCs (UNIDO, 2002/2003). These value chains, made possible by new technology, offer opportunities for latecomers to acquire the technology needed for participation and eventually to extend their role in these chains. Leading firms in advanced countries who control and drive these strategies by providing the technology have increasingly outsourced segments of these chains in order to lower costs and risks. In addition to strengthening their technological capabilities, latecomer firms also build links with that leading firms, learning from the latter specific organizational skills and market access, that are referred to as leveraging advantages (Prahalad & Hamel, 1990).

Latecomer firms connecting to GVCs initially become subcontractors using the original equipment manufacturer (OEM) business model (Hobday, 1995). These firms not only earn revenue, but through a gradual process of embedding themselves in GVCs, they build and strengthen linkages that enable them to ramp up their capabilities, including technological, and the country's industrial development (Mathews, 2006). Where production systems have not disintegrated and they are not connected with GVCs, latecomers face the challenging task of looking for strategic equivalents or seeking to work with international agencies to connect with GVCs.

Latecomer firms were able to achieve their first competitive advantage when they recognize their own weaknesses. The strategy Taiwan created took full account of these weaknesses. Thus, Taiwan sourced its technology, knowledge and market access externally. Entry through low-cost contract manufacturing enabled national firms to gain a foothold in the world's production chains. Latecomer resource acquisition strategies can be analyzed using insights from the resource-based theory of firms

(Mathews, 2002). The resource-based view of firms, as coined by Penrose (1959), argues that the fundamental competitiveness of firms lie in the critical resources that enable production and product diversification.

Specifically, the resource-based view argues that value is created if firms build their competitive advantage based on resources that are rare, non-imitable, and non-transferable (Barney, 1991). But this theory is not as useful when applied to latecomer capability building, given their severe “resource position barriers” (Wernerfelt, 1984). To characterize the types of resources to be targeted by latecomers, drawing from insights of the resource based view, Mathews (2002, p. 481) argued that latecomers should target external resources that are least rare, most transferable (e.g. through reverse engineering), and most imitable.

On top of that, the following stages are important for the latecomer firm’s strategic choices based on Mathews (2002, p. 476): (1) Using linkage as the initial step that generates opportunities for the latecomer firm; (2) Leverage resources to take advantage of the linkages established; (3) Out of repeated applications of linkage and leverage, learning is achieved and that enabled the latecomer firm to acquire dynamic capabilities.

Strategic shifts to outsourcing (i.e. OEM contracting) and technology licensing by incumbents in technology-intensive industries like the IC industry help create linkage opportunities for latecomers, of which opportunities for leveraging and learning may arise. Spillovers or externalities are therefore acquired by latecomers through linkages with foreign firms (Blomstrom & Kokko, 2001).

2.2.3 Latecomer Resource Acquisitions in Open Innovation Context

Changes in industries’ technological regimes, emergence of new scientific discoveries, and increasing innovation costs and complexities induce growth of specialized innovating firms engaged in different modularized activities and interacting with other

actors across GVCs (Grandstrand et al. 1997; Brusoni et al., 2001). Given increasing modularization in technologies, a firm can capture benefits from the entire economy instead of relying solely on internal capabilities, no matter how capable it is (Langlois, 2003: 375). This leads to the tendency of large firms giving way to specialized suppliers at the component-level and beyond (sub-components or knowledge or service inputs in intangible form) (Christensen, 2006). In time, it has also led to more prominent practices of open innovation in industries, which change the behavior of how firms in particular industries acquire external knowledge.

2.2.3.1 Open Innovation

Open innovation is defined as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively” (Chesbrough et al., 2006, p.1). The outside-in dimension of open innovation can be divided into four areas (Chesbrough, 2003): (1) managerial strategies to create, capture and share values via the business model, (2) transactions or networks, (3) capabilities or competencies, and (4) dealing with technological and market uncertainty through real options.

In the semiconductor industry, Christensen (2006) found that the organizational competencies of a system integration company, like Texas Instruments, depends on its capacity to reconfigure (1) its existing knowledge base (for example, via acquisitions and R&D integration) and (2) the mobilization of critical complementary innovative activities (such as chip design and marketing). Hence, in a vertically disintegrated industry, pursuing a core competency strategy with a strong inward orientation is not sufficient for firms to stay competitive.

Indeed, the literature on innovation management since the 1970s had already identified the notion of open innovation by addressing learning and innovation that cuts across

disciplines and organizational boundaries (Rosenberg, 1982; Rothwell et al., 1974; von Hippel, 1988; Lundvall, 1992; Rothwell, 1994; Pavitt, 1998). Hence, issues that have gained increasing traction include “how open is innovation” and “what determines the degree of openness” (Dahlander & Gann, 2010)?

2.2.3.2 Business Model and the Creation and Capture of Value

A firm’s business model works as a mediator between technological development (input) and economic value creation (output) (Chesbrough & Rosenbloom, 2002). Following Afuah (2004, p. 9), a business model is defined as “...the set of which activities a firm performs, how it performs them, when it performs them as it uses its resources to perform activities, given its industry, to create superior customer value... and put itself in a position to appropriate value”. Organizational strategies in business models determine the process of value creation and capture in open innovation systems (Chesbrough & Rosenbloom, 2002). It involves how firms strategize the creation of value jointly with the other partners.

Open innovation depends critically on value creation from innovation for a specific target group. A ‘value creating system’ (Porter, 1985, 1990, 1996) is a vertical value chain extending from suppliers to customers (Vanhaverbeke et al., 2008). Understanding the firm’s value chain and how it fits into the overall value system is key to the firm’s ability to achieve and sustain competitive advantage.

Open innovation can also be related to the concept of ‘co-opetition’ as articulated by Brandenburger and Stuart (1996). In an open innovation platform, strategic collaborations enable the creation of value for the partners involved as different parties integrate their various skills and competencies. Because the creation of value is undertaken by multiple actors, cooperation is essential. Brandenburger and Nalebuff (1996, p. vii) noted, however, that while value creation is cooperative, value capture is a

competitive process. The role of trust relationships based on a blend of competition and cooperation was articulated lucidly by Piore and Sabel (1984).

The “value constellation” concept is related to the value system as they emphasize the creation of value for customers (Normann & Ramirez, 1993). However, these two concepts differ in the way value is created. In the context of value constellations, firms pursue and practice collective competition, which means that competition is at the level of product offerings that the participating firms are collectively producing (Gomes-Casseres, 2003; Vanhaverbeke & Cloudt, 2006). Within each of these networks, a unifying vision is needed to bring partners together. Hence, leadership by a dominant firm presents within each network to govern and coordinate the group.

Open innovation can also be viewed from the perspective of transaction value (Zajac & Olsen, 1993; Dyer, 1997; Vanhaverbeke et al., 2008) rather than of transaction cost (Williamson, 1975, 1985). By participating in open innovation, firms seek to maximize the transaction value rather than minimizing the transaction costs. They may therefore take actions to achieve joint gains even if costs are not minimized (Zajac & Olsen, 1993, p. 138).

When attempting to commercialize technology, establishing a value network requires distinguishing and shaping the role of suppliers, customers and other parties in influencing the value captured from the act (Chesbrough & Rosenbloom, 2002, p. 534). An alternative view of value creation is “value co-production”. In this alternative value system, value is not simply “added”, but is mutually created and recreated by combining or reconciling different values among actors (Hampden-Turner, 1990; Ramirez, 1999).

Managerial strategies that shape organizational business models are therefore critical in this process. Not only are the innovating firms concerned with which and what types of technologies to be acquired from external sources (Vanhaverbeke & Peters, 2005), but

they are also concerned with how to leverage the externally sourced knowledge to create value for their customers and how to capture part of the resulting integrated value. Through strategic business models, firms also decide which innovations to be further developed in-house into products and which to be licensed out or divested as spin-offs (Vanhaverbeke et al., 2008). On the other side of the coin, latecomer firms are faced with increasing challenges of how to leverage on the external knowledge while securing and extending their role within the value system they operate in.

2.2.3.3 Resource Acquisition to Complement Internal Knowledge

As much as firms are increasingly placing more attention to source external knowledge through open innovation, studies have highlighted the importance of balancing the emphasis given to organizational ability to leverage on external knowledge and the organizational ability to build internal knowledge and technological capabilities (Chesbrough, 2003, 2006; Gassmann & Enkel, 2004; Vanhaverbeke et al., 2008). Combining internal and external sources of knowledge can deepen the technological capabilities of firms since the two are complementary to each other (Cassiman & Veugelers, 2002).

Cohen and Levinthal (1989, 1990) coined the term ‘absorptive capacity’, which can be understood from the perspective of four different dimensions, namely, acquisition, assimilation, transformation and exploitation of external knowledge (Todorova & Durisin, 2007).⁴ Internal R&D capabilities affect firms’ ability to recognize and monitor technological opportunities outside the firm; such capabilities are also crucial to facilitate those firms to exploit the external knowledge (Arora & Gambardella, 1994; Rosenberg, 1990; Cohen & Levinthal, 1989).

⁴ More discussion of organizational absorptive capacity is included in the latter part of this section.

2.2.3.4 Resource-Based View in Open Innovation Context

As discussed earlier, the resource-based view argues that firms should shape their competitive advantage to capture additional values by building or acquiring resources that are scarce, valuable and durable (Barney, 1991). The knowledge-based view is an extension of the resource-based view of Penrose (1959) by explicating knowledge as the most strategic and critical resource of firms (Spender, 1989; Nonaka, 1991; Conner & Prahalad, 1996; Grant, 1996). Hence, a sustainable competitive advantage of a firm is based on resources, more precisely knowledge, owned and controlled within the boundary of the firm (Dyer & Singh, 1998) and the differences between these firm-level resources explain differences in the level of performance among firms (Bierly & Chakrabarti, 1996).

The resource-based view also expounds the concept of nurturing core competencies as a strategy to sustain long-term innovative and competitive performance (Prahalad & Hamel, 1990; Sanchez & Heene, 1997). However, a question that attracts increasing scholarly attention in this sense is how to bridge the “introspective viewpoint centered on the firm itself” to the concept of open innovation (*Vanhaverbeke et al., 2008, p.9*). The concept of open innovation indicates that critical resources should not be closed off within the boundary of firms. The resources owned by independent firms have to be combined to create value for customers and the value network as a whole. With that, critical firm-level resources are extended beyond firms’ boundaries and resource flows (i.e. knowledge flows) take place among the firms participating in that value network.

Changing technological regimes and the rapid scientific and technical progress in high-tech industries inform us that knowledge is broadly distributed and that no individual firm can possess internally all the required sources for a new commercializable innovation (Hagedoorn, 1993; Powell et al., 1996). This fundamental shortcoming of

the resource-based view has gained increasing traction as more studies seek to emphasize that inter-organizational linkages promote learning, innovation, and the creation of new knowledge within firms (Kogut & Zander, 1992; Powell et al., 1996; Tsai, 2000).

Furthermore, research on open innovation has mainly focused on the interdependence of complementary knowledge in firms to introduce or commercialize a new innovative product (Vanhaverbeke et al., 2008). The study of latecomer catch-up requires other considerations to be included. While absorbing external knowledge and capturing part of the integrated value, latecomer firms need to technologically catch up to move up the value chain without compromising the overall value created for their customers. Throughout the process, the fundamental value created for customers may be altered as latecomer firms continuously fit themselves into the changing value system. It is important to re-examine the influence of resource-based view (i.e. the knowledge-based view) on latecomer catch-up literature by incorporating the concept of open innovation.

2.3 Organizational Studies

This sub-section reviews the relevant organizational studies by first discussing the key concepts in the theory of path dependence. It then explains why organizational absorptive capacity helps determine the organization's trajectory. Subsequently, it discusses the classical model of organizational path dependence advanced by Sydow et al. (2009). The section then explores the possibilities of path breaking or path creation by discussing about the role of 'vision' mustered by actors (entrepreneurs or individual leaders). The review goes beyond the organizational level and incorporates the concept of mutual reinforcement between an organization and the industry, which leads to coevolutionary lock in.

2.3.1 Path Dependence

To answer the question ‘why do firms differ’, ‘routine’ is the focal point in the formulation of evolutionary theory as expounded by Nelson and Winter (1982). Routine is defined as “.....most of what is regular and predictable about business behaviour.....especially if we understand that term to include the relatively constant dispositions and strategic heuristics that shape the approach of a firm to the non-routine problems it faces” (*Nelson and Winter, 1982: 15*). Because firms often stick to a path and do what they previously have done (Nelson & Winter 1982, p. 134-135), organizational routines can evolve into organizational path dependence in time.

The origin of the path dependence concept dates back to David's (1985) explanation of the ‘stickiness’ in the use of the QWERTY keyboard from a historical perspective. He noted that a path-dependent chain of events is one in which the outcome is the result of intervening events, some of which may while others may not occur by chance. These intervening events do not necessarily cancel each other out and are therefore "non-ergodic" - outcomes depend on the paths followed. Path dependence has found increasing acceptance in studies of social sciences (Lamberg & Tikkanen, 2006; Antonelli, 2008; Gruber, 2010), regional economics (Saxenian, 1994; Sydow et al., 2010), technological trajectories (Dosi, 1982; Dolata, 2009), and strategic management (Koch, 2011).

In theorizing ‘creative destruction’, Schumpeter (1942) postulated that any system that is optimum at a point in time will not remain the same over time. At the organizational level, organizations follow a certain path of capability building at any given point in time. That path defines the set of strategies available to the organization, and it also sets bounds around what the organization’s internal strategy set is likely to be in the future (Castaldi & Dosi, 2006). A firm’s technological knowledge base also does not deviate

too far or too quickly from its preceding direction because the firm's technical change follows along stable trajectories (Dosi, 1982; Pavitt, 1986). Therefore a firm's previous decisions on technological investments and set of routines limit its future technological behaviour (Teece, 1988). Path dependence is thus important to explain how firms' capability building differs since it depends on organizations' ability to balance between continuity of the existing paths and redirecting their capabilities by competitively breaking out of the path (Dosi et al., 2000, p.6).

Path dependence showcases the notion of 'moving forward', thus takes into account technological opportunities that lie ahead. Most research posit that the growth of an industry is attributable to the technological opportunities present. Technological opportunities available to firms are, thus, argued to be exogenous to the industry itself (Teece et al., 1997: 523). However, technological opportunities may actually be endogenous, i.e. the availability of technological opportunities is firm-specific since opportunities are often created by the innovativeness of firms themselves (Teece et al., 1997).

2.3.2 Absorptive Capacity

The dynamics of technological capability building at the organization-level affects significantly the catch-up process of latecomers (Amann & Cantwell, 2012). Absorptive capacity, which is defined by Cohen and Levinthal (1990, p.128) as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends", is largely a function of the firm's level of prior related knowledge. This view has been applied to study firm-level technological capability building in explaining the successful catch-up of Samsung Electronics (Kim, 1997) and Hyundai Motor (Kim, 1998).

Two features of absorptive capacity can affect the innovativeness of organizations. First, acquiring and accumulating absorptive capacity in an area at one point in time can lead to more efficient accumulation of knowledge in the future to assimilate and exploit any external knowledge. Second, the possession of a related knowledge base is crucial for firms to better evaluate the outcomes of developing new technologies by assimilating or appropriating certain external technological knowledge. Hence, absorptive capacity leads to the formation of expectations, while revised expectations in return help determine subsequent investment in more absorptive capacity, which affects the firms' R&D intensity (Cohen & Levinthal, 1990). Therefore, the development of absorptive capacity is itself path-dependent.

Organizations with higher levels of expertise or absorptive capacity are more sensitive to potential technological opportunities and they are more proactive in exploiting external opportunities (Cohen & Levinthal, 1990; 1994). This self-reinforcing mechanism that affects organizations' sensitivity to new technological opportunities helps explain why certain firms succeed while others fail at times when technological dimensions change.

2.3.3 The Sydow et al. Model

Building on David (1985, 1994) and Arthur (1989, 1994), the classical model advanced by Sydow et al. (2009) begins with an open search process (Phase I in Figure 2.1). As organizations progress from Phase I to Phase II, the model experiences a moment that sets path dependence into motion, i.e. the "critical juncture" (Collier & Collier 1991), when prior decisions activate a series of self-reinforcing loops that leads organizations to progress along defined patterns. In Phase II, if a reinforcing process is triggered and once a critical mass is achieved, the process can be irreversible. Options are then increasingly narrowed to the point where organizations no longer have choices. The

transition from Phase II to Phase III is therefore indicated by a 'lock-in' in Sydow et al.'s (2009) model. During this phase, organizations face rigidity in courses of action due to reasons, including high switching costs, sunk costs and monopoly. The state of path dependence is therefore caused by positive feedback mechanisms that lead to inefficiencies.

Sydow et al. (2009) distinguished path dependence from imprinting, structural inertia, or increasing commitment. However, strict demarcation is argued to limit the concept's empirical applicability (Manning & Sydow, 2011). To broaden the concept's applicability, it is helpful to extend it beyond the boundary of organizations and to incorporate concurrent movements in the industry.

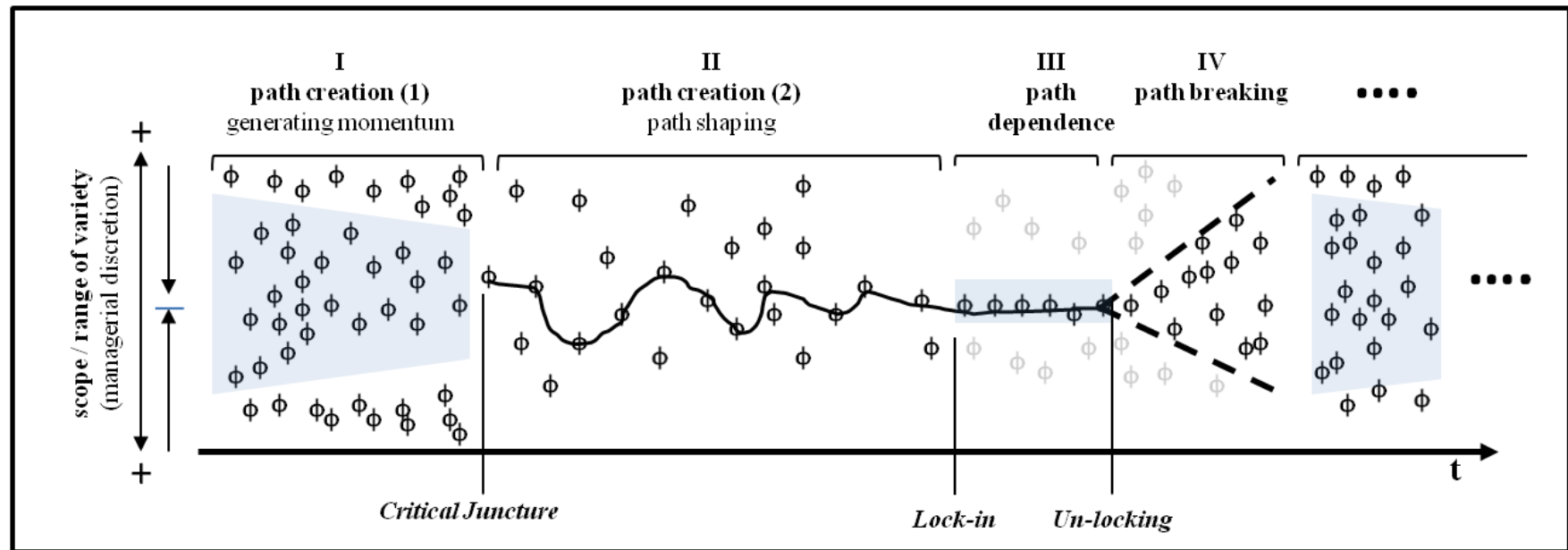


Figure 2.1: Organizational Path Dependence Model

Source: Sydow et al (2009).

2.3.4 Vision in Path Breaking and Path Creation

The overtone of determinism in most studies on path dependence has resulted in an over-emphasis on initial conditions without sufficient recognition of the potential of human will to unlock paths (Bassanini & Dosi, 2001). The entrepreneurial role in path breaking is conceptualized as ‘mindful deviation’ by Garud and Karnøe (2001) as entrepreneurs are the ones who break away from norms, by articulating and promoting new alternatives into organizations.

Path dependence is affected by the ‘state’ of variables including capabilities, visions, organizational set-ups, and their specific combinations, which are often influenced by strategic managerial discretions (Dosi et al., 2011, p.7). ‘Initial birthmarks’ and subsequent historical paths of organizations involving both operational repertoires and higher level collective visions - that help define the very identity of organizations - play key roles in the path-breaking process (Dosi et al., 2011).

Vision can be defined as a “set of beliefs in the firm regarding the its internal and external circumstances, the shape of things to come in the future, and, in the light of these, the way the firm should play its cards” (Fransman, 1999, p.54). While Swann and Gill (1993) view vision as a tactical and strategic means to achieve various corporate objectives, this study adopts Fransman’s (1994, 1999) notion that vision is constructed on a set of beliefs by the key decision-makers. With that, this study distinguishes the concept from the popular notion that vision is an indication of foresight, which is the ability to know what is required to achieve one’s objectives. Because vision-construction is led by entrepreneurs and it is capable of altering the orientation of a firm’s trajectory, it offers firms the opportunity to break from path dependence (Fransman, 1999).

2.3.5 Mutual Reinforcement, Coevolutionary Lock-In and Escaping from Path Dependence

Despite path dependence being largely driven by self-reinforcement, there can also be mutual reinforcement, i.e. interaction between ‘local’ and ‘population-level’ mechanisms (Dobusch & Schüßler, 2012, p.639). However, heterogeneity among industry agents and their imperfect adaptation within organizations and broader social networks lead to differences in pattern formation, which indicates that the system as a whole can never lock into a specific path (Coriat & Dosi, 1998; Bassanini & Dosi, 2001). Thus, while the coevolutionary nature of various socio-economic adaptations can be a source of lock-in, it also opens the door to major discontinuities and path de-locking.

Deviations from the status quo may bring about a coevolutionary response from interdependent actors, each with their own idiosyncrasies (Callon, 1986; Law, 1992; Latour, 1987). Coevolution takes place when two or more components evolve together but not in perfect harmony across time and space. The coevolving parts may, through negative or positive feedback, both enable and constrain each other.

In the study of the IC industry, most empirical works on coevolutionary reaction have focused on Intel (Burgelman, 1994, 1996, 2002; Burgelman & Grove, 1996, 2007) using firm-level longitudinal data. Burgelman posited that the path taken by Intel is an example of coevolutionary lock-in that has led to the firm’s success, which has been extremely dependent on microprocessors. Because the technological roadmap of Intel focused on the development of the next generations of microprocessors, deviations from the firm’s long-term technological trajectory is not easy.

As much as Intel enjoys virtual monopoly of the highest value component of personal computers (PCs), which allowed the firm the appropriation of rents in the industry, such

asymmetries generated positive feedback loops that cost Intel higher and higher investments to enable the adoption of newer microprocessors. Nevertheless, the complementary effects allowed Intel to control its external environment and influence the pace of the industry's technical progress (Pfeffer & Salancik, 1978). Being the driving force of the PC industry, Intel was able to dictate the tempo of changes in the other agents including customers, competitors, suppliers, and complementors. Intel's competitiveness also increasingly deepened the firm's knowledge base of the PC technology, thus constantly reinforcing the coevolutionary lock-in. In short, positive environmental feedbacks on Intel's choices of strategies intensified the relevance of the firm's selections, thus engendering high coevolutionary lock-in (Burgelman, 2002).

2.4 Summary

The notion of technological regime was first used to characterize the two models of Schumpeterian innovations (1934, 1942). The two different models are associated with two different Schumpeterian patterns of innovation that concern hierarchy of innovators, concentration of innovation activities and entry and exit of firms. Subsequent studies on technological regimes have sought to link the concept with different driving forces between upstream and downstream firms. There have also been studies attempting to explain how the driving forces lead to firms' choices of organizational boundaries, as well as, that show that different technological regimes present different catch-up opportunities for latecomers. However, what remains critically intriguing is the transitional process from one technological regime to another. While existing studies on technological regimes have generated significant impact on the concept of firm-level innovations, as the study has argued, it is important to integrate other concepts in search for a useful framework that can explain the mechanisms behind the transitional process for a better understanding of technological regimes. In so doing, the study posits that

transitions in technological regimes provide different environments at different points in time for latecomers to catch up and to leapfrog the incumbents.

Understanding changes in particular industry's technological regime is the fundamental basis to understand firms' innovative activities. Thus, they are highly relevant in understanding firms' technological catch-up. In the search to find out why some latecomers have successfully caught up while the others have not (despite attempting to pursue the same catch-up model), the study proposes that the remarkable catch-up story of Taiwanese foundries goes beyond the existing argument that latecomers' catch-up is a form of insertion into GVCs from where they sought to link, leverage and learn. The research proposition is, the Taiwanese latecomers have deployed different resource acquisition strategies in order to catch up and leapfrog the incumbents as the industry experienced different structural changes and progressed through different value systems. The concept of organizational core-competency becomes less prominent in an open innovation environment as the industry experienced structural changes.

The literature review goes on to include a brief discussion of the key concepts in the theorization of path dependence. The review also explains why organizational absorptive capacity helps determine the organization's trajectory. Subsequently, the classical model of organizational path dependence advanced by Sydow et al. (2009) is discussed. The possibilities of path breaking or path creation are explored by incorporating the role of 'vision' mustered by actors (entrepreneurial management). The review eventually discusses the concept of mutual reinforcement between an organization and its industry, which can lead to coevolutionary lock-ins.

Integrating the related concepts (e.g. path dependence, structural inertia and coevolutionary lock-ins) can be done by using positive feedback as an explanatory variable and as a conceptual bridge (Dobusch & Schüßler, 2012). Moreover, simulating

positive feedback mechanisms and boundary conditions at different levels of analysis provides a different but insightful perspective to the understanding of path dependence, as well as, the related concepts (i.e. avenues of escaping from path dependence). Because path dependence emphasizes that history matters, this study reckons the importance of conceptualizing the role of actors in creating history (Garud & Karnøe, 2001). However, if coevolutionary lock-ins enable a firm to control its external environment and to shape the progress of the industry, whereas ‘vision’ offers the possibilities of path breaking, actors can also lead firms to escape from organizational path dependence through coevolutionary lock ins since firms’ technological trajectory depends very much on the strategic interpretations of actors and its absorptive capacity. New technological opportunities can then become endogenous to firms with important managerial implications.

Therefore, conforming with Dobusch and Schüßler’s (2012) suggestion that the concept of path dependence should be applied appropriately instead of theorizing it simply as “a corset that is methodologically and conceptually too constricting” (p.639), this study integrates other concepts to stretch it beyond organizational boundary to explore the potential of coevolutionary lock-ins so as to escape from internal path dependence to explain firm differences. The evolutionary approach allows the study to conceptualize critical factors contributing to the role of actors (i.e. the entrepreneur or the individual leader) in the generative process of path creation or path breaking. We will then be able to know why TSMC has performed much better than UMC in the industry, despite a similar start-up and catch-up process.

CHAPTER 3

TECHNOLOGICAL REGIMES, ORGANIZATIONAL BOUNDARIES, AND INDUSTRY'S INNOVATION PATTERNS

3.1 Introduction

In this chapter, the research proposition being analysed is that transitions in technological regimes provide different environments at different points in time for latecomers to catch up and to leapfrog the incumbents. The chapter first presents the analytical framework for the research proposition and discuss the rationale behind the development of the framework; it then discusses the research methods used for this chapter. Subsequently, the chapter presents its findings, discussion, and summary.

3.2 Analytical Framework

The proposed framework in Figure 3.1 seeks to explain the transitions of technological regime in the technology-intensive IC manufacturing industry, under the condition that the environment is free of externalities. Because the focus of this chapter is to examine how the transitions of the regime are contingent on the actions of industry players, i.e. firms, the analysis is done on the basis that the processes take place under a static institutional environment with no path-breaking institutional forces aimed at interfering the industry's status quo. Six key dimensions that mould the technological regime of the IC industry were identified from the review of previous studies – technological interrelatedness, technological path-dependency, cumulativeness, degree of economies of scale, technological opportunities and technological appropriability.

Following earlier studies, these dimensions of technological regime determine the level of the key driving forces in the industry; namely technological interdependency, impact of technological discontinuities, gap of manufacturing capabilities and gap of

technological capabilities between downstream and upstream firms in the industry. These driving forces cause different impacts on firms' vertical boundaries, affecting their decisions to vertically disintegrate, specialize, outsource or vertically integrate, affecting the industry's patterns of innovation.

Firms' network systems are subsequently affected as firms respond to the patterns of innovations by strengthening their external linkages, creating a feedback loop to the technological regime. The external linkages are formed to 'fortify' the firms against their competitors to achieve synergies such as lower costs of R&D, secured supplies of components or locked-in customer orders. Smaller and specialized firms see the need to fortify themselves against the large and vertically integrated firms, i.e. the IDMs. Among the IDMs, firms expand their external linkages in order to strengthen or to maintain their leading positions in the industry. Firms' choices of external linkages and the consequent network system of each firm collectively interfere with the industry's status quo, resulting in changes in specific technological dimensions, and hence the overall technological regime. With the exception of a change of policy targeted specifically at interfering the status quo of a certain technological dimension (i.e. the emergence of a path-breaking forces), the technological regime of the industry evolves in a process described above.

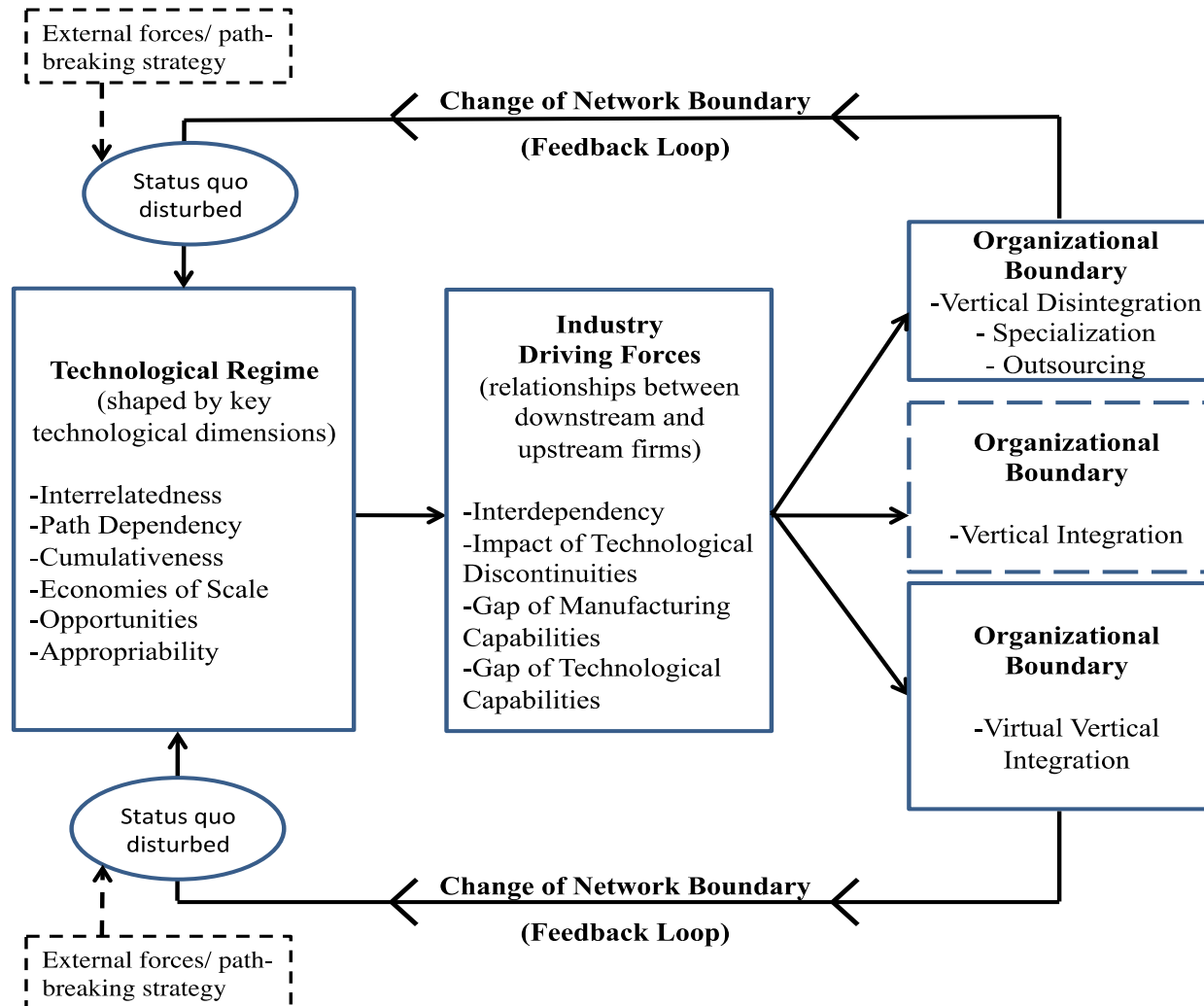


Figure 3.1: Changing Technological Regimes through Endogenous Transitions
Source: Authors.

3.3 Research Method

This chapter uses insights and information drawn from a number of interviews conducted from 2012 - 2013. The interviewees are industry experts who help us identify the key industry highlights during two different phases categorized in this chapter. The focus is on the period *after* the emergence of the fabless and foundry eco-system. The study focuses on examining how Taiwanese IC firms emerged late as pure-play foundries through vertical disintegration and by specializing among industry players. This period of time is referred to as Phase I, i.e. the period after the introduction of the first pure-play foundry and before the 21st century (1987 - 1999). On top of that, the major trends of the overall industry as direct impacts of the emergence of vertical disintegration or specialization are analyzed. This period is referred to as Phase II, i.e. the period after the 21st century (2000 - 2012).

To achieve internal validity and reliability, the key informants in this study represent different organisations, including technology or R&D institutes, government agencies, IC firms, market research firms, and academia. Multiple sources of evidence ensure the quality of the interviews and allow the researcher to maintain neutrality while capitalizing on each individual's information and insights (Yin, 1994, 2014). Table 3.1 lists the interviewees and their respective role in the IC industry.

The industry experts provided the study with important insights on the dynamics and specificities of high-tech manufacturing with a major focus on the IC industry. They also provided the researcher with perceived causal inferences and helped relate the details to the key concepts in the proposed framework. The findings are explained in paragraphs while the data gained from different reliable database providers are presented. The data corroborate the interview findings and work as useful conceptual indicators.

The focus of analysis for this study is the Taiwanese latecomer firms in the IC industry, specifically the pure-play foundries. More often than not, the study draws findings from the world's largest pure-play foundry –TSMC. TSMC was the world's first pure-play foundry and the firm has evolved to become the world's largest and most advanced logic IC foundry by the middle of Phase II, accounting for almost 50% of the industry's total market share.

To simplify the analysis of upstream and downstream firms, this chapter does not incorporate backend packaging and testing firms as the technological regimes that underpin back-end IC manufacturing and front-end IC manufacturing are different. Upstream firms are referred to as customers providing designs for manufacturing whereas downstream suppliers are wafer fabrication service providers. Vertically integrated IDMs are included into the analysis as these firms used to be the chip fabrication service providers to fabless firms, prior to the emergence of pure-play foundries. Furthermore, the foundry services are also offered to IDMs as the vertically integrated firms switch to the fab-lite model. Changing technological regimes will affect the interactions between the IDMs (suppliers) and the fabless firms (hence the upstream customers), as well as, the interactions between the IDMs (upstream customers) and the pure-play foundries (downstream suppliers).

This chapter organized the collected data from interviews by using the qualitative content analysis method as posited by Gläser and Laudel (2013). This method extracts and processes only the relevant data or information using categories derived ex ante from the theoretical framework. Patterns in the extracted data are identified and integrated into typologies (Yin, 2011). To ensure the classifications match both the theory and data, theory was modified throughout the process when needed.

Table 3.1: List of Interviews

Organization type	Organization	Position	Key expertise
R&D institutes/ Government agencies	1.Bell Laboratories, <i>New Jersey</i>	R&D engineer (1963-1989) ^A	Well known for co-inventing the non-volatile semiconductor memory which enabled the development of all modern electronic systems. He was asked by the Taiwanese government to return to Taiwan in 1990 to nurture engineering students.
	2.ITRI	From engineer in ERSO to President of ITRI (1976-2003) ^B	One of the seven engineers who was sent by the Taiwanese government to US in the 1970s to be trained under the RCA technology transfer programme.
	3.ERSO	Chief Director (late 1980s) ^C	Led Taiwan's largest and most ambitious National R&D 'Submicron Project'. The project developed Taiwan first 8-inch CMOS submicron manufacturing technology and transformed Taiwanese IC industry to global standard.
Academia	4.National Chiao Tung University (NCTU)	National Endowed Chair Professor and UMC Chair Professor ^A	Called by the Taiwanese government to return to Taiwan from Bell Lab in 1990 to nurture engineering students.
	5.Tsing Hua University	Professor of Technology Management, Morris Chang Chair Professor ^B	Taiwan's leading professor in Technology Management
IC Firms	6.Macronix	President ^C	Led Macronix to be the world's fourth largest IDM that specialized in non-volatile memory industry.
	7.TSMC	Senior Executive of Integrated Technology	The leader of the Integrated Technology division of TSMC. He has been leading the R&D and technological development of Moore's Law in TSMC for the past 16 years.
	8.Vanguard	Co-founder then President	Vanguard International Semiconductor (VIS) Corporation is a subsidiary of TSMC. It was co-founded by Morris Chang.
	9.UMC	Manager of Asia Sales Division and Business Management	A key leader in UMC's top management.

Table 3.1, continued: List of Interviews

Organization type	Organization	Position	Key expertise
		Two ex-senior engineers	Involved in UMC's R&D projects.
	10.Advanced Semiconductor Engineering (ASE)	R&D Director	Leads ASE's global R&D projects. Also a researcher in technology management. ASE is the world's largest and most advanced service provider of semiconductor packaging and testing.
Market research firms	11.CLSA Asia-Pacific Markets	Technology consultant and guest author for CLSA semiconductor technology reports (official email communications)	Semiconductor lithography. Besides professing at University of Texas (Austin), his experience ranged from working in established technological organizations including National Security Agency and SEMATECH.
	12.Macquarie Securities Korea Limited	Managing director – Korea Technology Hardware Research	Technology analysis of semiconductor industry.

Note: A, B, C = Change of professional roles in the industry.

Source: Interviews by authors, 2012 – 2013.

3.4 Findings

This section evaluates the empirical evidence of the industry's evolution using the analytical framework presented in the previous sub-section. The findings are presented according to Phase I and Phase II of the IC industry. Each phase is first presented with how a technological regime leads to the choice of organizational boundaries, followed by the feedback from the firms onto the technological regime.

3.4.1 Phase I: Technological Regime and Driving Forces in Choice of Organizational Boundaries

3.4.1.1 Technological Interrelatedness and Interdependency

The introduction of the fragmented business model heralded a technological revolution that changed the industry's landscape as fabless firms began to mushroom in the industry without having to inject lumpy investments into wafer fabrication facilities. Instead, the capital was spent on R&D and the firms' IPs would not have to be shared with giant MNCs again, which propelled the growth of fabless firms. As the industry was rather fragmented at this point, the interrelatedness (and so the interdependency) between fabless firms and foundries were considered lower as compared to Phase II.

3.4.1.2 Technological Cumulativeness, Path-Dependency and Impact of Technological Discontinuities

The IC industry is a knowledge and technology intensive industry that has been governed by Moore's Law since the introduction of the theory by the co-founder of Intel in 1965. Moore's Law states that transistor density in ICs doubles while the minimum line-width halves approximately every two years (Dubash 2005). The IC industry is therefore considered as technologically cumulative as firms are driven by the

law, which requires that a firm's development of a smaller technology node acts as a guide to its future development of subsequent nodes.

SEMATECH developed the first National Technology Roadmap for Semiconductors (NTRS) in the early 1990s. The roadmap identified the key technology challenges for the US integrated circuit industry to keep up with Moore's Law. SEMATECH was originally driven by the US-member firms. By 1999, it renamed itself International SEMATECH and expanded its membership to include global semiconductor manufacturers. Over the years, it has regularly updated the roadmap and has significantly expanded its scope (CLSA Research, 2012). Firms in the IC industry progressed at Moore's prediction and firms built their capabilities following the predefined technological trajectory. Consequently the development of the IC industry is also path-dependent.

Where technological cumulativeness and path-dependency are high, the event of technological continuities tends to have a larger impact to the firms' decisions in vertical boundaries. However, no major technological discontinuity took place during Phase I. As will be discussed later, technological cumulativeness and path-dependency have a more critical role when the industry evolves into Phase II.

3.4.1.3 Economies of Scale and Resulting Capability Gap Among Manufacturers

In the IC industry, a high degree of economies of scale has always been important to regulate the wafer fabrication process. However, when compared to Phase II, the degree of economies of scale required in Phase I is lower than that of in Phase II. Therefore in Phase I, the gap of manufacturing capabilities between manufacturers is smaller.

3.4.1.4 Technological Opportunities and Resulting Technological Capabilities

In Phase I, intellectual property (IP) vendors already existed although was not popularizing, and physical design tools were available from third-party electronic design automation (EDA) vendors which enabled system designers to freely develop their own chips and fabless firms without investing into manufacturing facilities to emerge (Saito, 2009). Because the costs of designing became significantly low due to the easy availability of design tools and fabless firms diverted virtually all their resources into chip designing and R&D, innovations became easier. Thus, technological opportunities were high in Phase I.

Given high technological opportunities and the fact that the fabless firms were still emerging in the industry, any new and small design house in the industry could have similar innovation opportunities. Hence there was no clear distinction between fabless firms and foundries in terms of their technological capabilities.

Although a very large foundry arm of an IDM can avoid such problems, IDMs had to choose spending on design over spending on production. Hence many IDMs in the industry eventually experienced a switch towards a fabless model, in which their chips of increasingly smaller nodes are now outsourced to pure-play foundries that continue to invest in more advanced wafer fabs.

3.4.1.5 Technological Appropriability and Resulting Technological Capabilities

The IC industry is considered as having lower appropriability in Phase I when compared to Phase II. Although Intellectual Property (IP) vendors existed at that time, the appropriation of IPs was less intense among the industry players. As the number of transistors on a chip incessantly increases due to the miniaturization process, the smallest process node was 0.18 micron meter by the end of 1999 and there was 1 million transistors placed on a single chip (ITIS, 1999). Due to the rapid technological

progress, the complexity of Large Scale Integration (LSI) design increased and the conventional ways of using Standard Cell or Full Custom to design millions of ‘gates’ became almost unviable towards the end of Phase I. Figure 3.2 shows that there has been an increasing design gap between the number of available gates in silicon and the number of utilized gaps, indicating that there is a huge gap between the capability to design and the capability to produce.

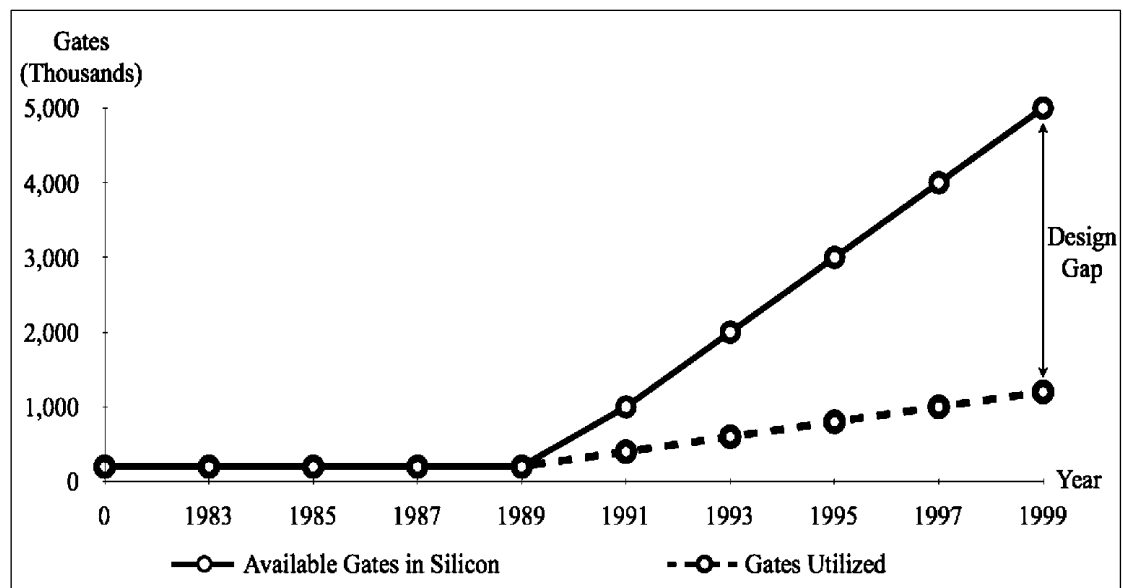


Figure 3.2: IC Design Capabilities and IC Production Capabilities

Source: Industrial Technology Information Services (ITIS), 1999.

IP began to become an efficient tool to manage and to reuse technologies. The use of IP was further induced when firms in the industry faced difficulties to meet the order-lead times had they designed everything in-house as the types of applications were also broadening. Because the trend of using IP was merely emerging towards the end of Phase I and firms were yet to exploit the advantages of IP, the appropriability of innovations was considered low. The low appropriability condition indicates that there were no major firm significantly controlled the use of IPs in the industry at that time. Such condition therefore indicates that there was no major gap of capabilities between the downstream and the upstream firms.

3.4.1.6 Organizational Choices of Vertical Boundaries and Industry's Patterns of Innovations

The abovementioned technological regime induced the consequent driving forces and has overall increased the demand for independent foundry services. Such conditions motivated more firms to enter as foundries, more IDMs to outsource their production or to vertically disintegrate in order to specialize. These in turn induced the growth of fabless firms in the industry and motivated more entries of IP vendors and design houses. In other words, the industry experienced further disintegration and small firms emerged specializing in different vertical scopes. The industry was observed as experiencing less stability in the hierarchy of innovators, high level of entry and exit thus low concentration of innovations.

3.4.2 Phase I: Feedback on Industry's Technological Regime

When the industry has low stability of innovators, high entry and exit thus leading to low concentration of innovations, it is found that smaller and specialized firms tend to strengthen their external linkages through strategic alliances, JVs and R&D consortiums. However, such activities are less aggressive in Phase I when compared to Phase II.

Before the 1990s, the IC industry was still dominated by IDMs. As the IC industry experienced vertical disintegration throughout Phase I, the production of IC was significantly disintegrated into specialized IP providers, design service firms, EDA vendors, chip prototyping companies, IC foundries for wafer-fabrication, packaging and testing firms.

These firms responded to the industry's patterns of innovations by strengthening their external linkages. In Phase I, the target of external linkages by foundries was the IP providers (ITIS, 1999). Foundries at this juncture began to form strategic alliances with IP providers or design houses besides maintaining the basic Cell Library in order to

ensure more comprehensive supplies of application-specific-intellectual-property (ASIP). Because barriers of entry into System-Level-Integration were high, the Taiwanese foundries strategically formed alliance with IP vendors and began to build their 'IP Libraries'. Strong development of IP support within the foundries subsequently fed back to the technological regime and affected concepts such as technological opportunities and appropriability.

TSMC began to involve in various IP alliances, including the IP Library Alliance, the EDA Alliance, and the Design Center Alliance. TSMC has since been well-known for its services in IP compilation. The compilation contains TSMC's own IP as well as the industry's largest library of third-party IPs. Designs for third parties are tested in TSMC and each design must comply with TSMC design rules and models. IP alliance members sold their IPs directly to TSMC; the designs were then stored by TSMC. Customers paid TSMC to look through the library to choose the designs to be used. The alliance members who sold the IPs were also under contract to support their individual IP by providing each customer's specific wafer design and business model. The EDA Alliance which consists of leading EDA firms compiled a set of process technology files to simplify the design process. Some selected members of the alliance established close collaborations with TSMC's design technology services team to implement TSMC's designs.

To ensure higher manufacturing accuracy, TSMC also introduced Unified Design for Manufacturing (UDFM), which was developed through strategic collaborations with EDA and other partners specialized in design infrastructure. TSMC provided its customers with unified access to its foundry data and the copy of its factory tool chain and process models. This method effectively compensated for the increasing manufacturing complexities and variances in advanced process technologies.

To accelerate chip prototyping to production and to shorten design cycle time, TSMC developed a free IP prototyping programme - Quickstart. The programme includes a pool of free IPs from TSMC and its selected third-party providers. Hence, qualified customers did not have to pay licensing fees to IP providers until their design begins manufacturing. Customers' risk was significantly lowered since customers received prototypes at no cost. The IP portfolio was built from TSMC's internal IP portfolio, as well as, TSMC's IP partners including Cadence Design Systems, Mentor Graphics and Barcelona Design. The programme worked simultaneously with TSMC's Cybershuttle programme; the prototype designers can have cost-sharing with other parties over a common mask set.

The abovementioned strategic alliance combined service capabilities and capacity which dramatically helped reduce the risks of manufacturing, design, and schedule of foundries' customers. In sum, the alliances allowed TSMC to forge strong working relationships with its customers and such alliances increased the interdependency between the foundry and its upstream customers due to vital mutual benefits, e.g. cost and R&D. The study will subsequently discuss how these organizational choices in return change the industry's technological regime.

3.4.3 Phase II: Technological Regime and Driving Forces in Choice of Organizational Boundaries

From the earlier discussion on Phase I of the IC industry, strategic alliances with a wide diversity of customers and solid establishment of IP infrastructure significantly strengthened the technological capabilities of foundries and changed the industry's technological regime.

3.4.3.1 Technological Interrelatedness and Interdependency

Phase II of the industry is considered as having higher technological interrelatedness, especially when IP vendors, design houses and fabless firms needed to work closely with foundries. As manufacturing processes became more complex, numerous challenges existed due to reasons including signal integrity, timing closure and power dissipation (CLSA Research, 2012). These complexities have caused design firms to adopt the concept of ‘design for manufacturability’. Figure 3.3 shows that in Phase II, design complexity significantly outpaced productivity. A closer relationship with the foundries is required to make practical and feasible designs.

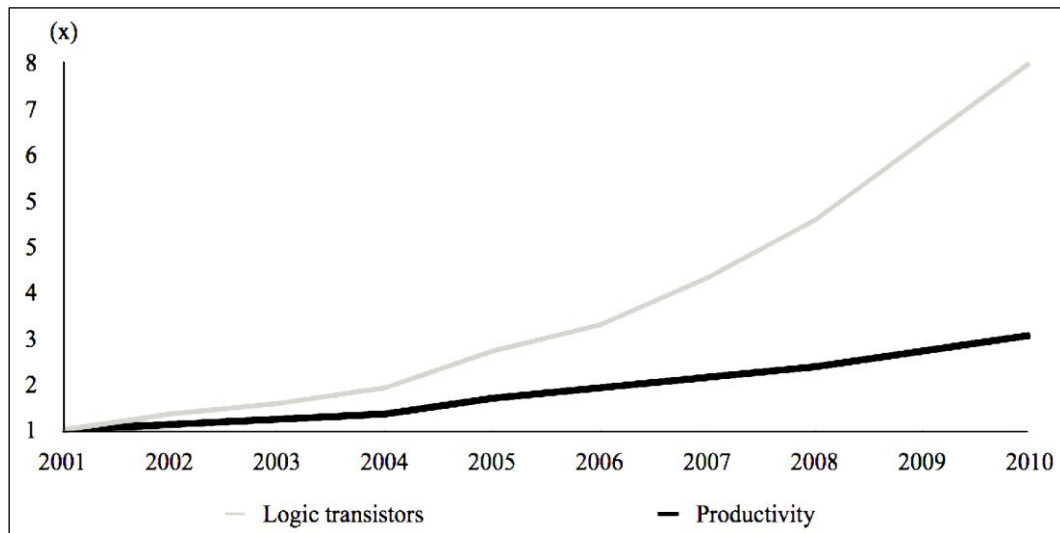


Figure 3.3: Design Complexity and Productivity (normalized to 2001 level)

Source: CLSA Research, 2012.

While manufacturing poses one challenge, a bigger challenge came from the changes in market demand. Integrated products that satisfy various needs of consumers, such as, memory, computing, wireless communication and entertainment were trending the market during Phase II. IC design firms therefore needed to develop more integrated chips to keep device sizes small and costs low. Concepts like system-on-a-chip (SOC) were gaining more appeal during the beginning of Phase II.

Hence, it was imperative for IC design houses or fabless firms to develop a more system-based approach rather than continuing with the ‘part-of-a-solution’ strategy (CLSA Research, 2012). These firms established closer working relationships with foundries that have stronger IP libraries thus allowing them to be exposed to various technologies thus enjoy stronger R&D capabilities.

Due to the continuous miniaturization process, the development costs for ICs were increasing (see Figure 3.4). More specifically, the proportion of development costs from masks and design was rising sharply (see Figure 3.5) which affected competitiveness of foundries. Rising costs of masking and designing discouraged IC designers from designing their products on multiple foundry processes. Thus the fabless-foundry relationship had to be strengthened and the interdependency between these firms was high. TSMC has benefited from this trend due to its having a large customer base, scale, technology capabilities and service infrastructures.

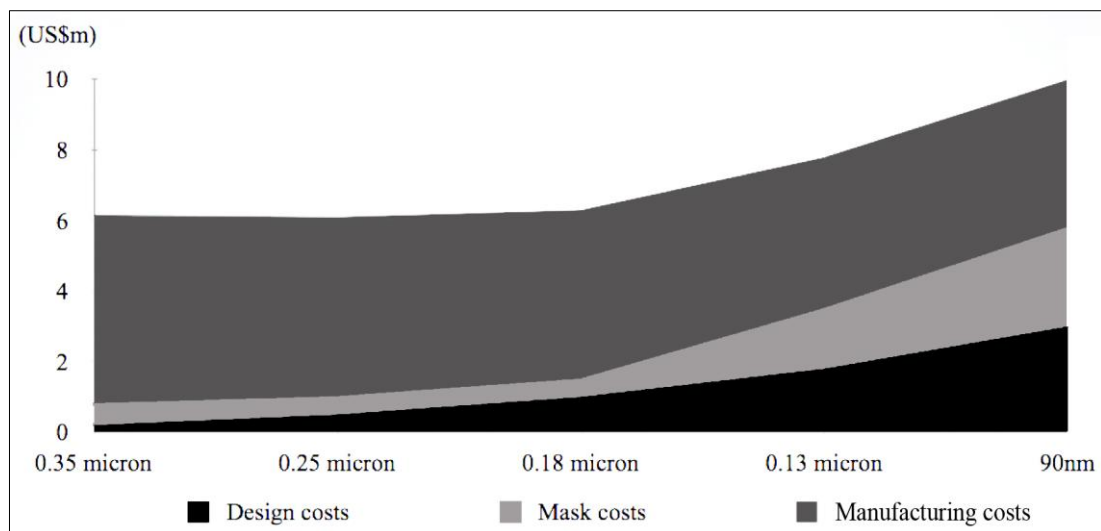


Figure 3.4: Total Development Costs at Different Process Nodes

Source: CLSA Research, 2012.

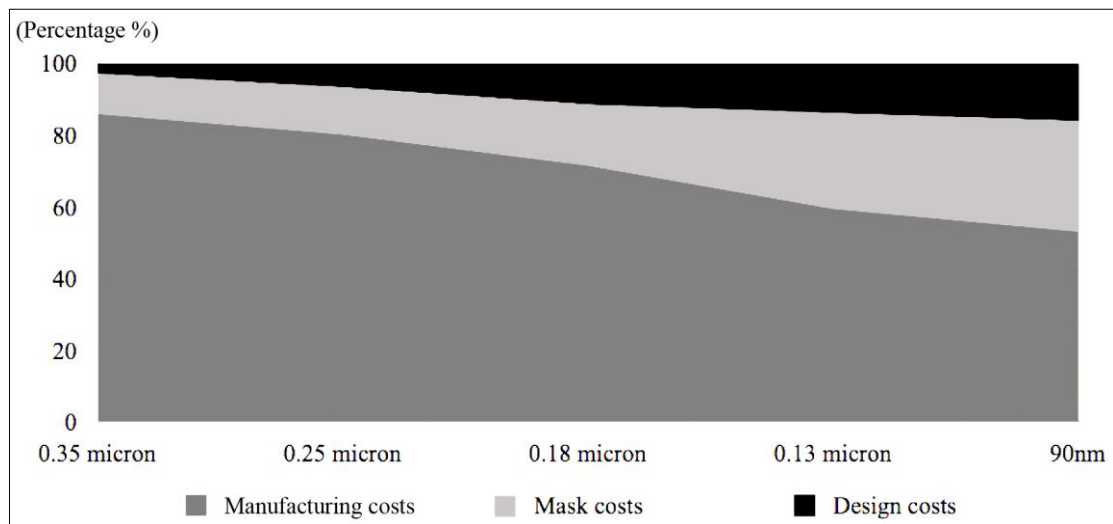


Figure 3.5: Breakdown of Total Development Costs at Different Process Nodes

Source: CLSA Research, 2012.

3.4.3.2 Cumulativeness, Path-Dependency and Impact of Technological Discontinuities

As the IC industry progressed, more miniaturized process nodes required higher accumulation of technological capabilities in firms in order to keep up with the advancements. However, technology migration to finer geometries no longer allowed the same cost savings, as foundries were challenged with increasing capital intensity. The transition beyond 28 nanometre (nm) became especially difficult to smaller and less advanced firms. Reaching commercially viable yields coupled with the ever increasing capital intensity (as a result of expensive lithography tools) made it difficult for the IC industry to continue relying on the migration to finer geometries at the wafer-level process in order to achieve cost savings.

When there is high path-dependency, large resourceful firms resort to virtual vertical integration for prevention of production bottlenecks. Large foundries such as TSMC began to vertically integrate their scope of R&D and ventured into advanced 3D packaging. This is one of their strategies in looking for technological discontinuities to

help mitigate technological bottlenecks. Because the industry has become highly path-dependent throughout the years, new discoveries like 3D packaging can replace the conventional ways of chip packaging and cause major impacts to the packaging incumbents. Therefore the impact of technological discontinuities at Phase II can be very high.

3.4.3.3 Economies of Scale and Resulting Gap of Manufacturing Capabilities

Economies of scale is a crucial force in IC technological advancement. A 200 millimetre (mm) wafer produced with the 180nm process costs approximately US\$1,600 to manufacture. Migrating that same chip to the 130nm process only add 5-10% to the wafer manufacturing cost, but it doubled the number of good dies yielded off that wafer, bringing cost-per-die down by almost a factor of two (CLSA Research, 2012). To keep reducing costs, the industry also migrated the wafer size to larger diameters which can hold more chips. For instance, moving from 200mm (eight inch) to 300mm (12 inch) wafers increased the cost of processed wafers by approximately 67%. However, the wafer area and the number of dies per wafer increased dramatically by 125% which yield a 30% net cost reduction at the chip level. Due to the same design but with a more mature process technology, the yield on the wafers increases because there is less edge-loss and there are more obtainable chips.⁵

Defect density, rather than yield, is another key determinant of an IC factory's manufacturing capabilities. Yield can be misleading due to the various die sizes. Smaller die sizes can achieve higher yields given the same defect density. In other words, if foundry production process technology remains unchanged, IC firms can reduce chip costs by shrinking die sizes.

⁵ Edge-loss refers to the percentage of dies lost due to the edge of the wafer cutting of the printed design (CLSA Research, 2012).

At the beginning of Phase II, the technology differences between the foundries and the IDMs were not significant enough to retain the IDM orders. However, when the technology gap widened towards the mid of 2000s as foundries aggressively moved to 12-inch wafer production and their advancement to 0.13-micron technology, IDM insourcing became increasingly difficult. Due to the widening technological gap between foundries and IDMs, IDMs eventually outsourced a larger portion of their production to the foundries as they need to use the foundries' advanced processes.

Where foundries experienced structural change, such as, the aggressive move to a 12-inch wafer and the advancement to 0.13-micron technology, economies of scale became so high that it induced most other firms to be very stringent with their manufacturing capacity including the IDMs. The 12-inch technology was a big entry barrier for the IDMs because the scale of a 12-inch fab could cause overcapacity to IDMs. A full-scale 12-inch fab is approximately two to three full-scale 8-inch fab in terms of output of silicon area (CLSA Research, 2012). Most IDMs did not need that much of capacity and migrating into such capacity could decrease their economies of scale. The uncertainty of the industry cycle and of demand also caused many IDMs to refuse committing to a 12-inch facility. At this juncture, large foundries like TSMC which moved aggressively into 12-inch production had higher manufacturing capabilities as compared to those IDMs.

The other driving force for IDM's outsourcing is the comparable manufacturing capabilities enjoyed by the fabless firms. Fabless firms have outgrown the IC market as a whole and substantially outpaced the growth of the IDMs since the beginning of Phase II. Sales of fabless companies in 2000 grew approximately 68% while IDMs grew approximately 39% (Gartner, 2013). Fabless firms use foundries' advanced and efficient processing as a base for their technology to gain market share. These firms mainly compete on the basis of better and more cost effective designs. These competitors of

IDMs, i.e. the fabless firms, were using 12-inch (300mm) fabrication facilities as a competitive advantage to gain market share in Phase II (30% cost saving per wafer compared to 200mm facilities) (CLSA Research, 2012). That eventually further induced the IDMs to also use 12-inch just to be as competitive. That was one of the critical times when IDMs became more aggressive in outsourcing to foundries.

To sum up, large foundries, with strong support of their fabless customers through strategic alliance, have outpaced the IC industry since the middle of Phase II. Further, their efficiency and advanced technology have attracted the IDMs to outsource part of their production. Fabless industry growth outpaced that of the IC industry with stellar sales growth of 68% in 2000 and the fabless firms accounted for approximately 70% of foundry revenue (CLSA Emerging Markets, 2005). By 2010, the fabless industry was a US\$ 73.6 billion industry (see Table 3.2 for the ranking of firms). The fabless industry continues to grow and the firms constantly outsource their chip fabrication to foundries. However, due to Taiwan foundries' leadership in technology and fabless firms' flexibility, IDMs were also forced to outsource part of their production. In 2000, IDM's outsourced \$3billion worth out of the global \$206billion of IDM revenue, approximately 1.5% of total IDM production.

Table 3.2: World's Top 25 Fabless Firms, 2010-2011

Rank	Firm	Origin	2011 Revenue	2010 Revenue	2011 Growth Rate (%)
1	Qualcomm	U.S	9910	7204	38
2	Broadcom	U.S	7160	6589	9
3	AMD	U.S	6568	6494	1
4	nVidia	U.S	3939	3575	10
5	Marvell	U.S	3445	3592	-4
6	MediaTek	China	2969	3590	-17
7	Xilinx	U.S	2269	2311	-2
8	Altera	U.S	2064	1954	6
9	LSI Corp	U.S	2042	1616	26
10	Avago	Singapore/U.S	1341	1187	13
11	Mstar	China	1220	1067	15
12	Novatek	China	1198	1149	4
13	CSR	Europe	845	801	5
14	ST-Ericsson	Europe	825	1146	-28
15	Realtek	China	742	706	5
16	HiSilicon	China	710	652	9
17	Spreadtrum	China	674	346	95
18	PMC-Sierra	U.S	654	635	3
19	Himax	China	633	643	-2
20	Lantiq	Europe	540	550	-2
21	Dialog Semiconductor	Europe	527	297	77
22	Silicon Labs	U.S	492	494	0
23	MegaChips	Japan	456	337	35
24	Semtech	U.S	438	403	9
25	Smart Mixed-Signal Connectivity (SMSC)	U.S	415	397	5

Source: IC Insights, 2012.

3.4.3.4 Technological Opportunities and Resulting Technological Capabilities

In Phase II, production became more efficient when carried out in independent foundries rather than in IDMs. From the perspective of technological capabilities, the foundries used to be behind the top-tier IDMs, which defined the most advanced process technology. However, since the beginning of Phase II, foundry process technology has caught up with that of the top-tier IDMs, and in some cases, exceeds that of many IDMs (see Figure 3.6). This is due to their ability to invest in leading-edge equipment and capability to develop process development in the down cycle of the

industry. Thus, foundries in Phase II were actually leading the industry process roadmap, according to the International Technology Roadmap for Semiconductors (ITRS). Leading designers have chosen the foundries to prototype some of their new circuit designs.

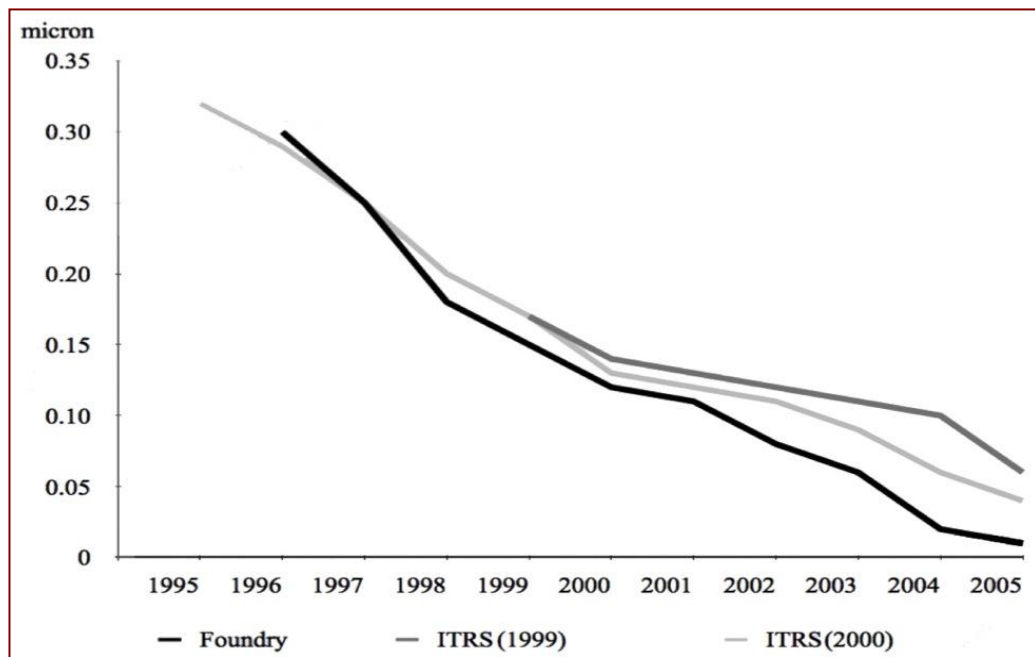


Figure 3.6: Process Nodes of Foundry versus Process Nodes of ITRS (IDMs)

Source: CLSA Research, 2012.

The process development cost for each smaller node in Phase II is shown in Figure 3.7. As the R&D cost for miniaturization has been increasing dramatically, technological opportunities of the industry were no longer abundant as not every foundry has such high financial resources as firms progress through Phase II. Moreover, the technologies became highly complex so that not every R&D project brings positive results. At this juncture, in the pure-play foundry segment, only large and advanced firms that have accumulated high technological capabilities, sufficient financial resources and strong R&D alliances could continue to miniaturize its process nodes.

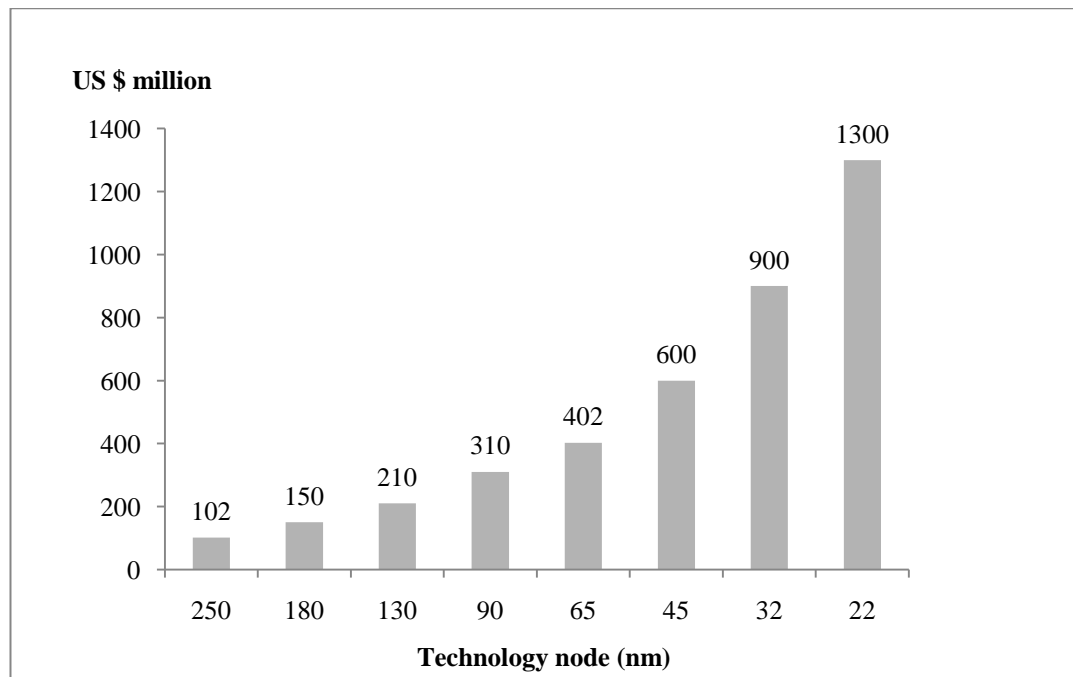


Figure 3.7: Process Development Cost by Technology Nodes
Source: CLSA Research, 2012.

Consequently, there was a diverging trend between the large and small foundries in the industry. On the one hand, the industry has become concentrated as the four largest foundries, i.e. TSMC, UMC, Semiconductor Manufacturing International Corporation (SMIC) and GlobalFoundries, were tapping a total market share of 68% by year 2011 (Gartner, 2013). The industry's largest foundry, TSMC, even began to integrate partly through various strategies. On the other hand, the smaller foundries in the industry remained highly fragmented and continued to command very minimal market shares.

3.4.3.5 Technological Appropriability and Resulting Technological Capabilities

In Phase II, the use of IP became popular and it was a necessary tool among large IC firms. Figure 3.8 shows that in Phase I, the conventional ASIC (application-specific-integrated-circuits) designs were through the use of Cell Library where there was only a minimum use of IP. Whereas in Phase II, the use of IP became critical in order to minimize the design time, to optimize at system level and to reuse the elements. Hence, the IC industry experienced high appropriability during Phase II.

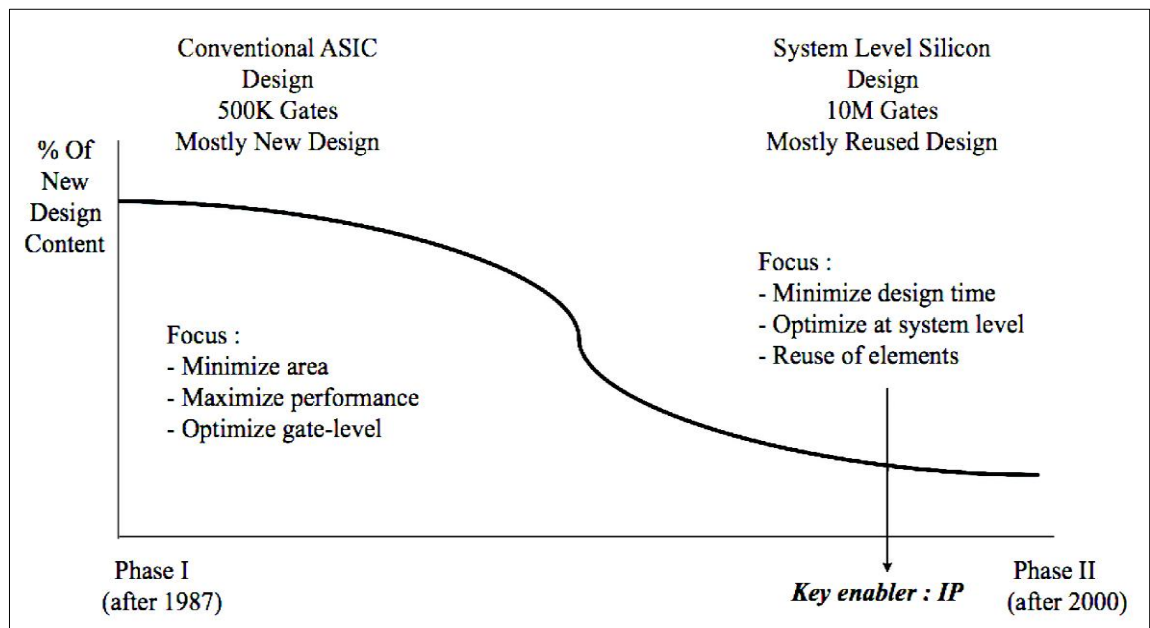


Figure 3.8: The Transformation of IC Designing, Phase I and Phase II

Source: ITIS, 1999.

3.4.3.6 Organizational Choices of Vertical Boundaries and Industry's Innovation Patterns

Low technological opportunities among smaller firms but high appropriability among the larger firms further consolidated the industry. High degree of economies of scale also propelled firms to be highly concerned with their manufacturing capabilities, which include efficient utilization of their production capacity. Technologically, IDMs are at least at par with foundries. IBM Microelectronics, Toshiba and Fujitsu were among the top in the list in terms of leading-edge IDM foundry-service providers. IBM re-launched its foundry-service group within the Microelectronics division in June 2001 and has since attracted a group of leading fabless companies to utilize its manufacturing services. Historically, many IDMs have offered foundry services to fill their capacity, including Texas Instruments, LSI Logic and Japanese IDMs which have been offering foundry services to competitors in Japan such as Toshiba, NEC and Oki Electrics.

On the other hand, there were also IDMs which moved towards a fab-lite model. Figure 3.9 shows that more and more IDMs have transformed into the fab-lite model as the industry experienced further miniaturized process nodes. In May 2009, TSMC and Fujitsu announced a partnership on process technology production for the manufacture of Fujitsu's products. Under the agreement, the mass production of the 40nm generation of logic products would be outsourced to TSMC. This is in line with Fujitsu's broad strategy to move to a fab-lite model and its decision not to upgrade its facilities in Japan. The two firms were also doing a joint research on 28nm and smaller technologies (CLSA Research, 2012). Fujitsu's migration to an asset-light model enabled it to focus on its strengths in the miniaturization process and on promoting businesses that leverage design technologies on its existing customer base. The importance of software continued to increase, as the company used its strength in software development to improve its SoC LSI devices.

TSMC's extensive R&D has resulted in a wide range of technical expertise as well as service offerings. The firm possesses one of the most extensive process technology portfolios, giving it the ability to serve a wide range of customer needs ranging from embedded memory to advanced radio frequency-related processes. In addition to its advanced manufacturing capabilities, TSMC also has one of the most extensive service-related technology offerings, including design-for-manufacturing to advanced photo-masking services, forming a true one-stop-shop total solution IC foundry offering.

130 nm	90 nm	65 nm	45 nm	28 nm	22 nm
Intel	Intel	Intel	Intel	Intel	Intel
Samsung	Samsung	Samsung	Samsung	Samsung	Samsung
IBM	IBM	IBM	IBM	IBM	
STMicro	STMicro	STMicro	Crolles alliance	Crolles alliance	
Panasonic	Panasonic	Panasonic	Panasonic	Panasonic	
Crolles alliance	Crolles alliance	Crolles alliance	Renesas		
Renesas	Renesas	Renesas	Texas Instruments		
Texas Instruments	Texas Instruments	Texas Instruments	Toshiba		
Toshiba	Toshiba	Toshiba	NEC		
NEC	NEC	NEC	Fujitsu		
Fujitsu	Fujitsu	Fujitsu			
AMD	AMD	AMD			
Motorola	Freescall	Freescall			
Infineon	Infineon				
Sony Philips	Sony NXP				
Cypress	Cypress				
Sharp	Sharp				
Hitachi					
Mitsubishi					
Siemens					
ADI					
Atmel					
On Semi					
Rohm					
Sanyo					

Figure 3.9: Number of IDMs in the IC industry at miniaturized process nodes

Source: CLSA Research, 2012.

3.4.4 Phase II: Feedback on Industry's Technological Regime

When the industry has high stability of innovators and low number of entrants but with high a high number of exits, the highly concentrated innovations provide large firms the opportunity to strengthen their external linkages in order to secure their leading position. To counter TSMC's strengths, Samsung participated in the Common Platform Alliance, which is a unique foundry model developed together with IBM and GlobalFoundries in the State of New York. Each of the firms sent hundreds of their process development engineers to work together at Albany Nanotech and IBM's 300mm wafer fab in East

Fishkill, New York. Enabled by the Common Platform technology collaboration, this alliance is dedicated to developing CMOS technology in order to standardize the process technology across the production fabs of the three firms. Began at the 90nm process node, this collaborative R&D has progressed to 65nm, 45nm, 32/28nm and 20nm process nodes.

Following the Common Platform Alliance, TSMC and Samsung also participate in a joint development called the Global 450 Consortium, together with IBM, GlobalFoundries and Intel. The five firms committed to a \$4.4B investment in New York State (CNSE, 2012). To support the R&D project, the State of New York invested \$400 million in the State University of New York (SUNY) College for Nanoscale and Science Engineering (CNSE) in Albany.⁶ Furthermore, Intel also decided to build its 450mm East Coast Headquarters to provide support to the project management in Albany. The consortium plays a crucial role in moving the IC industry to next generation wafer size – 450mm.

Besides strategic alliances to develop smaller process nodes and a larger wafer diameter, giant firms in the industry further fortify their positions by developing advanced technologies to mitigate the impacts of the slowing Moore's Law. Through a strategic alliance with Xilinx, a global leader in programmable logic solutions, TSMC was able to introduce chip-on-wafer-on-substrate (CoWoS) technology on a commercial scale to fabless firms like Xilinx. CoWoS can generate a more than 30% of cost savings; while for dies larger than 600mm, CoWoS can realize a 60-90% cost reduction – providing a strong incentive for customers to adopt this new technology (CLSA Research, 2012). By 2012, almost 50% of chips larger than 120mm were transforming to adopt CoWoS. Other economic and technical benefits associated with CoWoS technology include superior performance, lower power consumption, improved heat dissipation, cost

⁶ CNSE is a unit of the University at Albany, one of the four University Centers of the SUNY College (CNSE, 2012). The allocated R&D amount is also inclusive of \$100 million for energy efficiency and allowances for low cost energy.

savings, flexible designs, shorter time-to-market, and the de-bottlenecking of Moore's Law.

In return, Xilinx was the first firm to announce the commercialization of 2.5D through-silicon-via (TSV) technology with its Virtex-7 series FPGA, i.e. a chip that can be programmed to carry out specific functions (CLSA Research, 2012). Due to the new technology, for the first time, dies can be sliced and placed side-by-side instead of stacked on a single package for applications under 28nm. Power consumption is reduced by 50%, providing a significant cost advantage over previous generation FPGAs. The new technology development has allowed for significant cost reduction, achieved by enhancing yields during wafer-level manufacturing processes. This strategic alliance between TSMC and Xilinx again intensify the technological interrelatedness (thus interdependency) between the downstream and the upstream firms. Furthermore, concepts of technological regime such as degree of economies of scale and technological opportunities will be impacted.

Given the technical difficulties and higher capital intensity required for these types of technologies, strategic collaborations across players of different scope are becoming critical. TSMC is leading the technology of CoWoS among pure-play foundries, aiming to provide a one-stop-center business model to penetrate into mid-end and back-end businesses. UMC, the world's third largest pure-play foundry, partnered with Elpida and Powertech to develop alternative 3D IC packaging by leveraging their expertise in wafer, memory and packaging respectively (CLSA Research, 2012).

The technology alliance, based at IBM's facility in East Fishkill, New York, includes Global Foundries, IBM, Infineon Technologies, Renesas Electronics, Samsung Electronics, STMicroelectronics and Toshiba. Members of the Common Platform Alliance (i.e. IBM, GlobalFoundries and Samsung) collaborated with

STMicroelectronics to develop and standardize advanced 28nm process technology with the objective to streamline global manufacturing for electronics and device producers.

In these advanced processes and technologies, only a very few IDMs and foundries can afford the required R&D expenses and equipment costs. Only Intel, Samsung and TSMC emerged as the dominant companies manufacturing on 28nm nodes and below. Given the limited number of competitors and TSMC's early lead in CoWoS technology, the innovations of the foundry industry is becoming even more concentrated.

Foundries, especially the larger ones, have the advantage of volume over IDMs. Not all IDMs enjoy the same advantage, but they are increasingly forced to choose between spending resources on design and spending resources on production. As nodes transition to smaller geometries, an unstoppable movement towards a fab-lite model continues to take place because these IDMs face limited resources. Only two IDMs - Intel and Samsung – are able to survive this at and beyond the 22nm process node (CLSA Research, 2012). Compare that to 16 IDMs at the 90nm node, or 10 IDMs at 45nm – the demand for foundry services will dramatically rise (Figure 3.9).

3.5 Discussion

The question of how technological regime affects the possibilities of catch-up has been rather left open in the existing catch-up literature. The catch-up process can be examined from a broader perspective – the industry technological regime determines the possibilities for the occurrence and process of catch-up. The emergence of the pure-play foundry model was a disruptive organizational innovation. When the industry was transiting from the vertical integration model to the vertical disintegration model, higher technological opportunities but lower technological appropriability result in a smaller gap of capabilities between the newly emerged pure-play foundries and small IC design houses. Such dimensions of technological regime allow small firms to work together

through strategic alliances to overcome and catch up with the large incumbents (i.e. the vertically integrated firms). However, because a vertically disintegrated industry also leads to a smaller technological gap among the outsourced firms (i.e. pure-play foundries), small and new firms face stiff competition with each other (see Table 3.3). These conditions symbolize the Schumpeterian Mark I patterns of innovation. The transition took place when smaller firms, i.e. the pure-play foundries, began to seek strategic alliance with IP providers, EDA vendors and design houses to grow larger – creating a feedback loop that changes the industry’s technological regime (see Table 3.4).

Choices of organizational boundary affect firms’ strategies to form external linkages. In Phase I when the IC industry experienced vertical disintegration, small and specialized firms sought to form external linkages that help overcome what they lack. However, due to the specific technological dimensions and dynamic driving forces as discussed, these firms remained highly specialized and the value chain of the industry was highly modularized. Nevertheless, in time, strategic collaborations in the industry caused impacts to the industry status’s quo in a cumulative manner that changed the industry’s technological dimensions. In Phase I, the choices for external linkages and network boundary caused the industry’s technological interrelatedness, cumulativeness and production scale effect began to rise (see Table 3.4). The industry subsequently progressed to a different technological regime.

When a technology-intensive industry transits to virtual vertical integration as large and specialized firms integrate their activities, a higher degree of economies of scale, lower technological opportunities and higher technological appropriability can provide a promising environment for latecomers to leapfrog vertically integrated incumbents in order to become industry leaders. Although begun as a pure-play foundry, TSMC has managed to achieve successful industry and technological leadership in Phase II.

However, it can be observed from Table 3.5 that there was then a smaller technological gap between the pure-play foundries and the large incumbents in Phase II. A wider technological gap among the pure-play foundries also means that only large and advanced firms get to survive and the industry was concentrated. The environment symbolizes Schumpeterian Mark II characteristics, with higher barriers of entry and higher stability of innovators. The transition cycle goes on when larger firms in the industry seek strategic alliances to grow even larger. External linkages among larger and more advanced firms in Phase II caused the large but specialized firms to be closely ‘networked’ with other players in the industry (see Table 3.4).

Table 3.3: Phase I – Transition to Mark I

Dimensions of technological regime	Driving forces (direction of impact)				Resulting organizational boundaries	
	Relationships	Outsourced firms with SD firms	Outsourced firms with VI firms	Among outsourced firms (foundries)	VI firms	SD firms
Lower interrelatedness	Interdependency	Lower (+)	Lower (+)	N.A	Disintegrated/ outsourced	
Higher path-dependency and cumulativeness	Impact of technological discontinuities	N.A (no major technological discontinuities in Phase I)				
Lower degree of economies of scale	Gap of manufacturing capabilities	N.A	Wider (-)	Smaller (+)		
Higher opportunities	Gap of technological capabilities	Smaller (-)	Wider (+)	Smaller (-)		
Lower appropriability	Gap of technological capabilities	Smaller (+)	Wider (-)	Smaller (+)		

Note* VI = vertically integrated, SD = specialized designing, N.A = not applicable.

Source: Authors, interviews.

Table 3.4: Feedback Loop from Firms and the Endogenous Transition Process

Phase	Firm choices of organizational boundary	External linkages	Network boundary	Effects on industry status quo	Impacts on technological dimensions
Pre 1987	Vertical integration	The first pure-play foundry emerged in 1987. The existing cycle was broken and the technological regime changed.	Closed innovation.	Fabless firms began to outsource to pure-play foundries.	Interrelatedness began to increase; cumulateness decreased; economies of scale decrease; opportunities increased; appropriability began to increase.
Phase I	Vertical disintegration (outsourcing)	Foundries seek strategic alliances with IP providers and design houses.	Modularized and specialized; emphasized organizational core competency but participated in strategic collaborations.	Certain foundries grew large with strong IP library.	Interrelatedness increased; cumulateness increased; economies of scale began to increase; opportunities and appropriability increased.
		Foundries seek strategic alliance with EDA vendors.		Unified design for manufacturing was introduced. Fabless firms design according to foundries manufacturing rules.	
Phase II	Virtual vertical integration	Common Platform Alliance by IBM, Samsung, Global Foundries; Global 450 Consortium.	'Networked' specialized firms; emphasis on organizational core competency and open innovation practices that lead to the integration of external and internal knowledge.	To develop smaller technology nodes; to migrate to 450mm wafer diameter.	Interrelatedness, cumulateness, economies of scale and appropriability increased and became even higher; opportunities decreased.
		Strategic alliance between the largest pure-play foundry (TSMC) and the largest fabless firm (Xilinx).		To develop 3D advanced packaging (CoWoS).	

Source: Authors, interviews.

Table 3.5: Phase II – Transition from Mark I to Mark II

Dimensions of technological regime	Driving forces (direction of impact)				Resulting organizational boundaries		
	Relationships	Outsourced firms with SD firms	Outsourced firms with VI firms	Among outsourced firms (foundries)	VI firms	SD firms	Outsourced firms (foundries)
Higher interrelatedness	Interdependency	Higher (+)	N.A	N.A	Exited or disintegrated (fab-lite) to form VVI with downstream and upstream firms	Outsourced and grew larger to form VVI with downstream and upstream firms	VI to form VVI with downstream and upstream firms or remained small and fragmented
Higher path-dependency and cumulativeness	Impact of technological discontinuities	Impact of technological discontinuities is higher on SD, VI and outsourced firms in Phase II (+)					
Higher degree of economies of scale	Gap of manufacturing capabilities	N.A	Smaller (-)	Wider (+)			
Lower opportunities	Gap of technological capabilities	Smaller (+)	Smaller (+)	Wider (-)			
Higher appropriability	Widening gap of technological capabilities (+)	Smaller (-)	Smaller (-)	Wider (+)			

Note* VI = vertically integrated, SD = specialized designing, VVI = virtual vertical integration, N.A = not applicable.

Source: Authors, interviews.

3.6 Summary

This chapter examines the mechanisms of the changing technological regimes. The framework shows how each technological dimension within a regime affects the industrial relationships between downstream and upstream firms. The framework is also used to explain how those changes lead to firms' strategies for their organizational boundaries. The analysis in this chapter also shows how choices of organizational boundaries affect network boundaries among firms, which eventually impacts relevant technological dimensions of the regime. The formation of industry's technological regime is endogenous as firms make choices to their organizational boundary that create feedback loops to different dimensions in that technological regime.

The findings in this chapter provide insights to how technological regimes shape industry innovation patterns and how they provide different environments for latecomers to catch up and leapfrog the incumbents. It also shows the transition process of an industry shifting its characteristics between Schumpeter Mark I and Schumpeter Mark II. As compared to the previous studies of Schumpeterian patterns of innovations, this chapter examines the transition mechanism by positing it as a process that goes through changing technological regimes, dynamic driving forces of downstream and upstream firms, and strategies for organizational boundary and network boundary.

Analyzing the technological transitions of an industry, especially a technology-intensive one, is fundamental and critical to understanding the related mechanisms including catching up, technological upgrading and capability building. This chapter has shown that choices for organizational boundary can lead to changing network boundaries that impacts the industry's status quo. Further analysis of how the changes in these boundaries can affect latecomers' resource acquisition process to catch up and leapfrog is important. These aspects are examined in the following chapter.

CHAPTER 4

RESOURCE ACQUISITION STRATEGIES AND CATCHING UP IN DIFFERENT VALUE SYSTEMS

4.1 Introduction

This chapter analyses the research proposition that the Taiwanese latecomers have deployed different resource acquisition strategies in order to catch up and leapfrog the incumbents as the industry experienced different structural changes and progressed through different value systems. The concept of organizational core-competency becomes less prominent in an open innovation environment as the industry experienced structural changes.

4.2 Analytical Framework

The purpose of the proposed framework in this chapter is to examine the catch-up process of latecomer firms as the industry progresses into different industry structures that change the value systems of networks. To systematize the analysis, Figure 4.1 shows how the study divides the period of analysis into different phases and spaces. The pre fabless-foundry era is the period before the emergence of Taiwanese pure-play foundries. The focus of this study is on Phase I where the industry experienced vertical disintegration, and Phase II where leading firms in the industry began to form virtual vertical integration. The analytical framework for this chapter is shown in Figure 4.2. The framework distinguished three different forms of industry structures, i.e. vertical integration, vertical disintegration and virtual vertical integration, and shows how the industry's value system varies at those changing industry structures.

The framework divides the interface between latecomer firms and incumbents into six dimensions throughout the different phases. The focus of this study is from vertical

disintegration to virtual vertical integration and the interface is divided into Dimension I, II, III(a), III(b) and IV(a) and IV(b). First, latecomers could have accumulated the back-end manufacturing capabilities when large MNCs relocated their production lines in less developed countries (pre-1980s). When firms in latecomer countries start to operate as contract manufacturers (Dimension I), they seek to acquire external knowledge from incumbents and MNCs that are technologically advanced in order to build internal capabilities. In time, the latecomer firms moved from Dimension I to III(a) and III(b) before arriving at the technology frontier – IV(b). Alternatively, the latecomer firm could have moved from Dimension I to Dimension II. This is the model posited in existing studies (e.g. Hobday, 1995), which argue that latecomer firms should begin as an OEM and upgrade to become an original design manufacturer (ODM) and eventually an original brand manufacturer (OBM). It is not the interest of this study to examine how a latecomer firm can upgrade from OEM to OBM. Existing evidence has also shown that this is often a difficult task for the latecomers. In fact, the proposed framework seeks to analyse how latecomers can arrive at the technology frontier without having to become an OBM.

The framework also seeks to highlight that, while the industry is progressing through different phases, the concept of organizational core competency in resource-based view also evolves in tandem with increasing practices of open innovation. However, such changes do not progress in perfect harmony with the changes in industry structure, but with slippages across time and space. The changes in industrial vertical structure and the practices of open innovation result in different value creating systems. The objects of analysis are therefore latecomer contract manufacturers seeking to catch up and leapfrog the incumbents as they progress through different dimensions. In most cases, the actor in this framework is a latecomer firm. However, in the absence of a latecomer firm, the

actor might be a public institute, such as Taiwan's ITRI before firms entered the IC industry.

Following the framework postulated by Mathews (2002, 2006), strategizing on how to find a gateway into the GVCs requires three stages, namely linkage, leverage and learning. Mathews (2002, 2006) have identified three key characteristics of latecomers' targeted resources: least rare, most imitable and most transferable. These resource acquisition strategies are included into the analysis in this framework to find out how latecomer firms shape their business models to offer values into their networks. In order to examine latecomers' resource acquisition strategies, it is also important to find out whether the types of targeted technologies are substitutable, have potential for growth and competitive. This study emphasizes that, across different dimensions, the latecomers' strategy of (re)inserting themselves into the GVCs requires strategic choices that allow them to create values for other actors within their value systems.

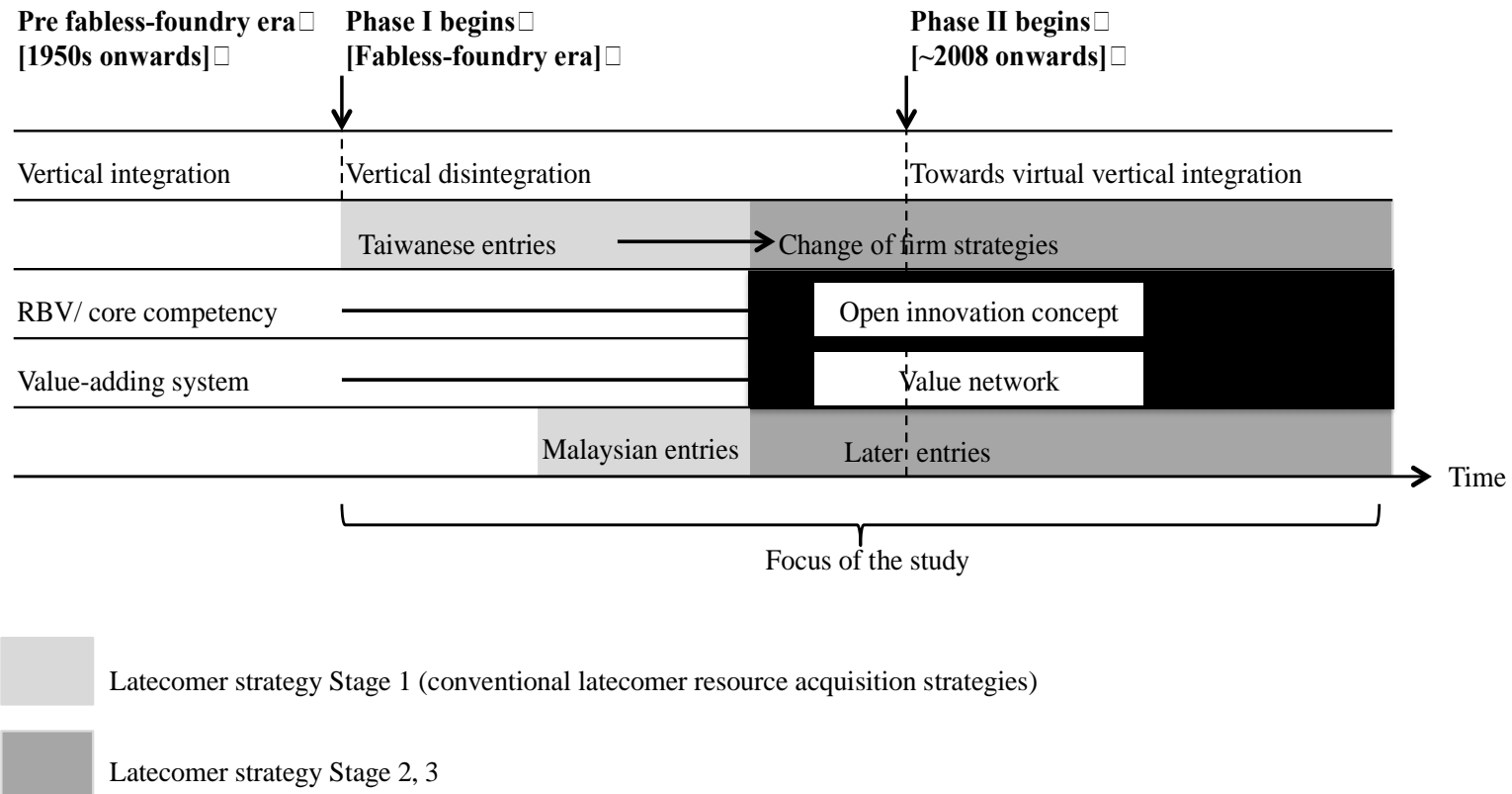


Figure 4.1: Changes in Industrial Structure and Value System, IC Industry

Source: Authors.

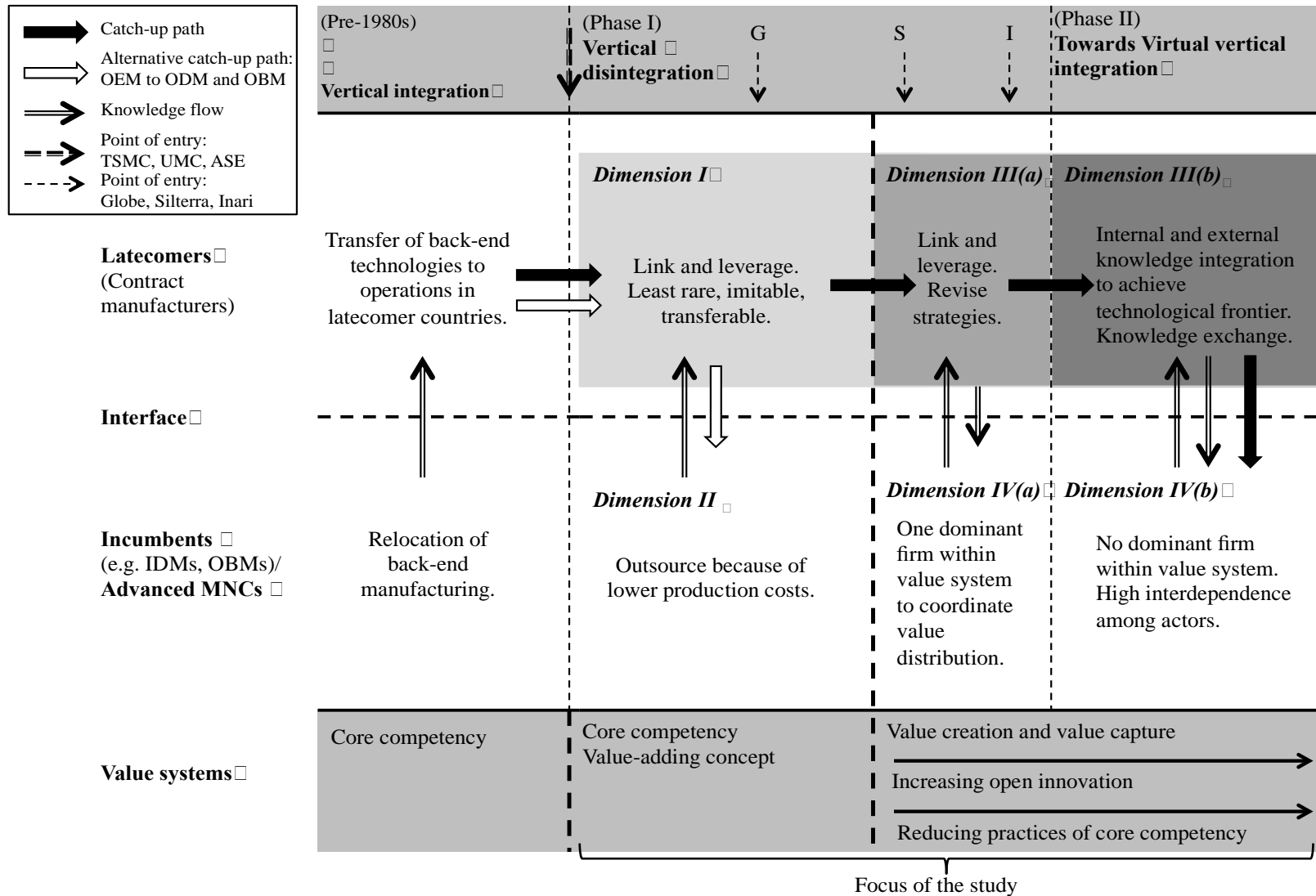


Figure 4.2: Latecomer Resource Acquisitions to Catch Up in Changing Value Systems
Source: Authors.

4.3 Research Method

In the light of the research gap identified earlier, this chapter uses six firm-level cases from two latecomer countries: TSMC, UMC, ASE, Silterra, Globetronics and Inari Amertron. Whereas TSMC and UMC are two Taiwanese front-end IC manufacturing firms that have successfully caught up and the former has become the world's largest pure-play foundry, the Malaysian owned IC foundry (i.e. Silterra) is a typical example of latecomers being trapped at lower tiers despite mimicking the Taiwanese business model. The objective of incorporating Silterra into the analysis is not to make direct comparisons, but to examine how the timing of entry (hence different industrial structures and value systems) affects the catch-up process. Only by examining both the successful and unsuccessful cases, the key determinants and firm-level strategic choices through different points in time can be identified.

To provide a stronger test of the framework, the study also incorporates Outsourced Semiconductor Assembly and Test (OSAT) firms as shadow cases to examine how the conditions vary for firms specialized in back-end production stages. ASE is Taiwanese largest OSAT whereas Globetronics and Inari Amertron are two Malaysian-owned IC OSATs that experienced growth since the 2000s.

The data collection for the proposed framework involves 26 interviews conducted from 2012-2013, with a major focus on organizations in Taiwan and Malaysia. The study examines the propositions by identifying the 'key informants' to be interviewed (Yin, 2014). In-depth semi-structured interviews were conducted and information was further updated via official email exchanges and phone calls with the key informants after the interviews. Table 4.1 shows the list of semi-structured interviews undertaken from 2012 – 2013 for the study.

To achieve internal validity and reliability, the key informants in this study represent different organizations (Yin, 1994, 2014). These industry experts provided the study with important insights on the dynamics and specificities of the IC industry. They also provided perceived causal inferences and helped relate the details to the key concepts in the proposed framework. The insights and information gained from the interviews are explained in paragraphs. Meanwhile, the study corroborates the interview findings with secondary data obtained from official records and statistical databases, including IC Insights, CLSA Research and Gartner. These data are especially useful to work as relevant indicators to the proposed concepts.

Similar to Chapter 3, this chapter organized the collected data using the qualitative content analysis method (Gläser & Laudel, 2013). Only the relevant data or information are processed using categories derived *ex ante* from the theoretical framework. The process helped us identify patterns in the extracted data and integrate them into typologies (Yin, 2011).

Table 4.1: List of Interviews

Organization type	Organization	Position
Technology or R&D institutes/ Government agencies	Bell Laboratories, <i>New Jersey</i>	1.R&D engineer (1963-1989) who co-invented the non-volatile semiconductor memory ^A
	Industrial Technology Research Institute (ITRI), Taiwan	2.Engineer in ERSO - President of ITRI (1976-2003) ^B
	ERSO, Taiwan	3. Chief Director (late 1980s) ^C
	Industrial Economics and Knowledge Center (IEK), Taiwan	4.Deputy General Director
	Science and Technology Policy Research and Information Center (STPI), National Applied Research Laboratories, Taiwan	5.Director General
	Northern Corridor Implementation Authority (NCIA) Technology Development Centre, Malaysia	6.Senior Manager, Manufacturing Division
	USAINS Infotech, Centre of Excellence for E&E, Malaysia	7.General Manager 8.Senior Business Development Manager
	Collaborative Research in Engineering, Science and Technology Center (CREST), Malaysia	9.Program & Research Director
	QAV Technology (Test lab and certification company), Malaysia	10.Managing Director
Academia	NCTU, Taiwan	National Endowed Chair Professor and UMC Chair Professor ^A
	Tsing Hua University, Taiwan	Professor of Technology Management, Morris Chang Chair Professor ^B
IC Firms	Macronix, Taiwan	President ^C
	TSMC, Taiwan	11.Division Leader at Integrated Technology 12.Senior Project Manager Co-founder then President ^C
	Vanguard (TSMC's subsidiary), Taiwan	
	Global Unichip Corporation (TSMC's design-service subsidiary), Taiwan	13.Account Manager
	UMC, Taiwan	14.Manager of Asia Sales Division and Business Management 15.Two ex-senior engineers
	ASE, Taiwan	16.R&D Director

Table 4.1, continued: List of Interviews

	Silterra, Malaysia	17.Chieft Executive Officer (CEO) 18.Senior Manager, Corporate Development & External Affairs
	X-Fab, Malaysia	19.Human Resource Director
	Globetronics, Malaysia	20.CEO
	Inari Amertron, Malaysia	21.CEO
	Altera, Malaysia	22.Senior Project Manager
	Malaysian Investment Development Authority (MIDA), Malaysia	23.Senior Executive
Market research firms	CLSA Asia-Pacific Markets	24.Technology consultant and guest author for CLSA semiconductor technology reports (official email communications).
	Macquarie Securities Korea Limited, South Korea	25.Managing Director – Korea Technology Hardware Research
	Samsung Economic Research Institute (SERI), South Korea	26.Chief Center Manager (Complex Systems Center)

Note: A, B, C = Change of professional roles in the industry.

Source: Interviews by authors, 2012 – 2013.

4.4 Resource Acquisition Strategies of Taiwanese and Malaysian Latecomer Firms

The study begins by examining how the latecomer firms from Taiwan and Malaysia have, in the earlier stage of their catch up, deployed different organizational strategies to shape their business model and to target the types of technologies they acquire. The technology targeted by these latecomers showcased specific characteristics. As discussed, organizational strategies help latecomer firms to create values for their customers, hence securing their role in the GVC. In time as leading firms in the industry seek to form virtual vertical integration, the value systems of the industry experience changes and affect the catch-up process of later comers. Firms that participate in more production stages open up themselves to more gateways to external collaborations in order to source more advanced knowledge.

4.4.1 Phase I: Vertical Disintegration

In Phase I, the IC industry experienced vertical disintegrations as fabless firms emerged and outsourced their production to specialized foundries and OSATs. As the industry progressed, large incumbent IDMs also began to outsource to these contract manufacturers. In Phase I, the Taiwanese latecomers entered into the GVC and their activities are discussed below as Dimension I. In the later part of Phase I, Malaysian latecomer firms began to enter the industry. These latecomer firms have pursued different catch-up strategies at different points of entry and as they progressed from one dimension to the other.

4.4.1.1 Taiwanese Latecomers

As both TSMC and UMC were spin-offs that were incubated from ITRI, their early productions were chips in calculators, watches, toys and musical cards. In 1976, ITRI and RCA began their agreement on a 10-year technology transfer from RCA to ITRI. The first 5 years were to transfer IPs and technologies whereas the remaining 5 years were to provide technical trainings.

According to Mathew (2002, 2006), the targeted technology during the initial stage of latecomer catch-up should be the “most imitable” and “most transferable”. However, as opposed to what was posited, the latecomer firms from Taiwan did not opt for least rare (most common) technology. At that time, the mainstream IC process technologies included N-type metal-oxide-semiconductor (NMOS), P-type metal-oxide-semiconductor (PMOS) and Bipolar methods. For instance, NMOS technology was led by large MNCs at that time, including AT&T and IBM. However, Taiwan’s Technical Advisory Committee (TAC) decided to transfer Complementary metal-oxide-semiconductor (CMOS) technology from RCA, which was a non-mainstream (most rare) technology at that time. CMOS was a newly developed technology in 1968.

During 1974 to 1975 when ITRI was discussing the technology transfer agreement, CMOS was not easily adopted in scale even in advanced firms. Both the US government and RCA agreed to transfer CMOS technology because CMOS was a non-mainstream technology and the transferred technology involved 7.5 micron process nodes, which was one generation behind RCA's most advance process node at that time – 5 micron.

TAC believed that transferring the CMOS technology could bring several advantages to Taiwan's IC industry at that time. Adopting a mainstream technology would have them face stiff competition with the incumbents at the initial stage of their capabilities building. Moreover, the Taiwanese foundries began by producing technologically obsolete chips of calculators, toys, musical cards and timing devices. The incumbents had ceased producing these chips at that time and hence viewed them as not posing any threat. As a result, Taiwanese foundries actually had 7 years to build internal capabilities before competing with large MNCs. Also, since CMOS was an emerging technology, it provided the Taiwanese latecomers the opportunities to leapfrog the incumbents if they managed to advance the practicability of CMOS technology. Nevertheless, TAC also requested RCA to transfer the NMOS technology, so as to have a substitute if CMOS could not work out – the “back-up” plan.

When the firms began to operate on their own, they deployed different resource acquisition strategies. During the initial stage of TSMC's catch-up (Dimension I), the firm has created a path for itself by introducing a new business model into the IC industry, i.e. the pure-play foundry. The firm ensured itself linkages to external MNCs by being a contract manufacturer of front-end wafer fabrication. The targeted customers were fabless firms or chip design houses. UMC was established in 1980 as an IDM but it began transformation to a pure-play foundry in 1995. During the initial stage of catch-up, TSMC acquired external knowledge from Intel as Intel provided training and

transferred its obsolete technologies to TSMC. UMC pursued a fast-following strategy. Although the firm only began transforming to the IDM model in 1995, the firm's technological capabilities were at par with TSMC in Phase I.

ASE was established in 1984 and specialized in back-end packaging and testing services, namely OSAT. It was considered a path creating strategy at that time, given that the business model of pure-play foundry was yet to be introduced. Moreover, the future prospects for outsourced contract manufacturing were considered to be unclear during the early 1980s. At that time, ceramic packaging was the mainstream technology for back-end manufacturing. However, ASE began its operations with the then non-mainstream technology, i.e. laminated packaging. Therefore, the targeted technologies were also considered to be rare. Although it was only an emerging technology, ASE faced stiff competition from major incumbent IDMs which had advanced packaging and testing technologies at that time.

4.4.1.2 Malaysian Latecomers

The Malaysian firms have pursued a path-following strategy to become a pure-play foundry. Silterra was incubated from MIMOS as a promising firm to follow the footsteps of successful firms like TSMC and started manufacturing as a pure play foundry in late 2000.⁷ Globetronics was a humble SME start-up in 1991 whereas Inari was established in 2006. Globetronics and Inari are two Malaysian firms that operate as OSATs, offering back-end IC packaging and testing services to advanced MNCs.

Entry by latecomers at different points in time denotes the different technology life cycle as faced by the latecomer firms. The point of entry for the Malaysian firms was the time when the telecommunication products began to boom. In late 2000, Silterra

⁷ The company was acquired by Khazanah - the government-linked investment corporation - in 2004 to provide additional capital for expansion.

began fabricating 0.25 micro CMOS chips. After more than a decade since the emergence of TSMC, CMOS had become the mainstream process technology. In 2005, SilTerra successfully fabricated 8MB SRAM chips using 0.13 micron CMOS technology through a strategic alliance with IMEC – a Belgium-based nanotechnology research center. Although Silterra's point of entry shows that advanced firms in the industry were already in Dimension III(a) at that time, Silterra lagged behind in Dimension I.

Globetronics started by serving a single customer and single manufacturing service to a giant MNC in Penang, Malaysia – Intel. Intel was a customer of, and partner and trainer to Globetronics. Intel also transferred critical knowledge to the latecomer at its initial stage of catch-up. Intel transferred operations systems and set-up, equipment and tool, human resource training, skills and technology transfer. Meanwhile, Inari Technology focused on the radio frequency (RF) mobile segment, including back-end wafer processing, package assembly, and RF testing. Its major customer was Avago Technologies. The Malaysian firms exemplify the characteristics outlined by Mathew's argument of beginning with the technologies that were the most common, imitable and transferable. Both Globetronics and Inari have used the relevant strategies in Dimension I and Dimension III(a) respectively at their points of entry into the industry. The findings for organizational business models and resource acquisition strategies of these firms in Phase I are summarized in Table 4.2.

Table 4.2: Phase I – Catching Up in a Vertically Disintegrated Industry

Phase I Vertical Disintegration		Taiwan			Malaysia		
		Front-end		Back-end	Front-end	Back-end	
		TSMC Dimension I	UMC Dimension I	ASE Dimension I	Silterra Dimension I	Globetronics Dimension I	Inari Amertron Dimension III(a)
Point of entry into GVC (Year)		1987	1980	1984	2000	1991	2006
Business model	Contract manufacturer	Pure-play foundry	Pure-play foundry since 1995	OSAT	Pure-play foundry	OSAT	OSAT
	Production specialization	Front-end wafer fabrication	Front-end wafer fabrication	Back-end packaging and testing	Front-end wafer fabrication	Back-end packaging and testing	Back-end packaging and testing
	Targeted customers	Fabless firms, chip design houses	Systems integration firms	Fabless firms, IDMs, systems integration firms	Systems integration firms	Systems integration firms	Systems integration firms, IDMs.
	End-consumer market	Calculators, watches, cards	Calculators, watches, cards	General electronics products	Smart phones	Timing devices	Personal computers and telcos
Resource acquisitions (Targeted technologies)	Rareness	Non-mainstream (CMOS)	Mainstream	Non-mainstream (laminated packaging)	Mainstream (CMOS)	Mainstream	Mainstream technology
	Imitability	Imitable	Imitable	Imitable	Imitable	Imitable	Imitable
	Transferability	Transferable	Transferable	Transferable	Transferable	Transferable	Transferable
	Substitutability	Yes	No	Yes	No	Yes	Yes
	Maturity (Life cycle)	Emerging (CMOS technology)	Emerging (CMOS technology)	Emerging demand for laminated packaging	Emerging demand for Display Driver ICs)	Maturity (Transferred from Intel)	Growing (wireless telco products)
	Competitiveness	No major incumbent in CMOS	Limited competitors adopting CMOS	Major incumbents exist	Stiff competition Major incumbents in CMOS, telecom products	Competitive	Competitive (Technological entry barrier was low)
Catch-up path		Path-creating	Fast-following	Path-creating	Path-following	Path-following	Path-following

Source: Authors' elaborations based on interview findings, 2012-2013.

4.4.1.3 Changing Value Systems

Towards the later part of Phase I (i.e. when Dimension III and IV began), smaller or less advanced firms in the industry began to participate in open innovations to gather and access external knowledge. Meanwhile, the industrial value-adding concept subsided among larger firms that are seeking to leapfrog advanced incumbents. Instead of just adding values to each production stage, these firms seek to co-create values with upstream and downstream firms. Due to stiff competition at the frontier of technology, these firms still emphasized organizational core competency and avoided collaborations that could narrow their technological gaps with competitors.

(a) The creation of collective values

ARM is a leading IP licensor for low-processor designs. The technological performance of its processors is not as high as Intel's, but its lower power consumption has allowed nearly 100% adoption of its processors in mobile devices as of 2012, including smartphones and tablets.⁸ Since Phase I, the driving force behind the progress of the IC industry, as well as the performance and power convergence between Intel and ARM is a combination of the increasing performance and lowering the cost of an IC. Advanced pure-play foundries have played a significant role in meeting this critical requirement. The competition among the advanced pure-play foundries has driven the speed of node miniaturization and has pushed the limits of process nodes. More importantly, these manufacturing technologies are made available to fabless customers in the industry. Technical analysis by industry experts show that, while the cost of designing and manufacturing chips increases with every new technology generation, the performance and the functionality of the chips increase at a faster rate (see Figure 4.3). Therefore, the

⁸ ARM earns revenue from upfront license fees. The firm does not sell its own chips. Instead, it provides its clients access to certain microprocessor or core designs and subsequently collects royalties per IC sold in the market that incorporates its design. The high development costs and long period of development time are amortized across many IP licensees (CLSA, 2012).

cost per function of the chips actually decreased over the years, allowing the industry to continue to progress.

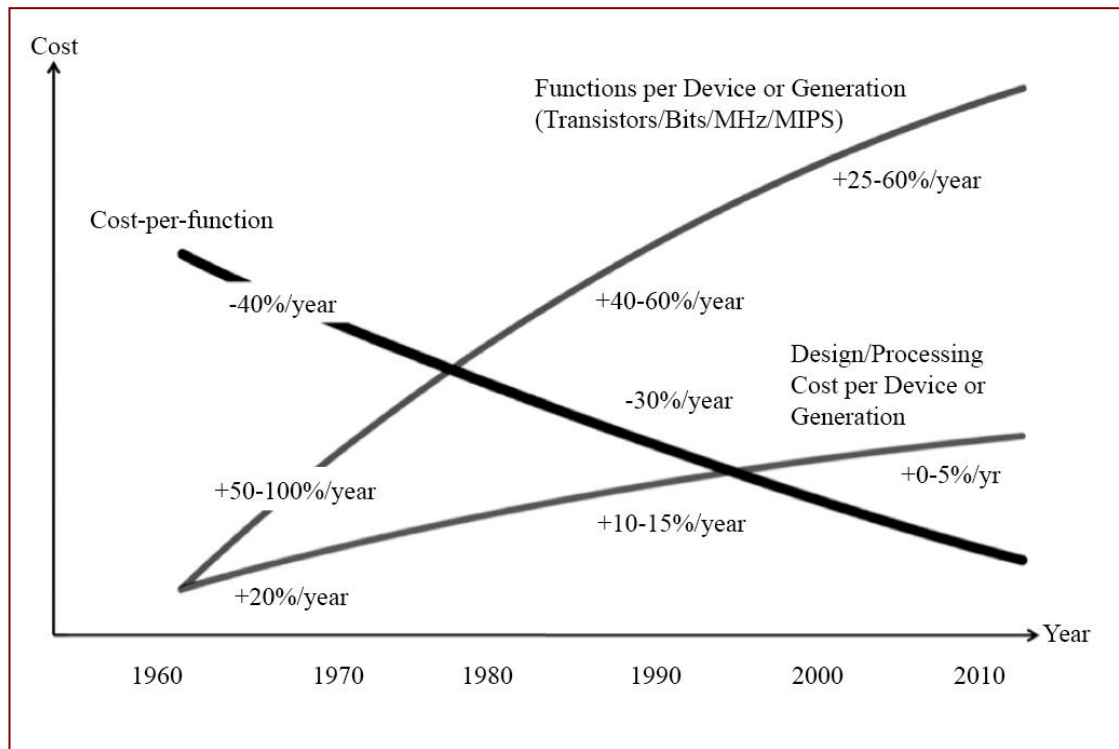


Figure 4.3: Collective Engine that Drives the IC Industry
Source: IC Insights, 2014.

Shrinking the circuit geometry on a chip improves the performance and functionality of the transistors while reducing power consumption. However, reducing the circuit geometry on a chip to allow more transistors to fit in a given area requires a combination of a few key areas of innovation, including transistor design, interconnect technologies, patterning or lithography, and packaging. This means that, in order for firms to gain both increasing performance and cost reduction so that they could progress, upstream and downstream firms within the value network have to collaborate closely in order to achieve the collective values.

(b) Collaborations to keep up with technology competitions

As the development costs for new generations of process node keep increasing, practicing open innovation has also provided critical advantages to firms aiming to keep up with the race for process miniaturization. IC firms in the industry have formed strategic alliances and participated in cooperative organizations towards the end of Phase I to leverage from third parties the required manufacturing technology, assets, tacit knowledge and experience, scale to shorten new process development time, lower manufacturing costs, and reduce time-to-market. Based on technical analyses by industry experts, innovations through collaborations helped reduce the process development costs for firms. Figure 4.4 shows the difference in overall cost for a firm to develop a new process node individually as compared to firms that develop the technology in a consortium, taking into account technology, assets, knowledge, scale, time, and manufacturing costs.

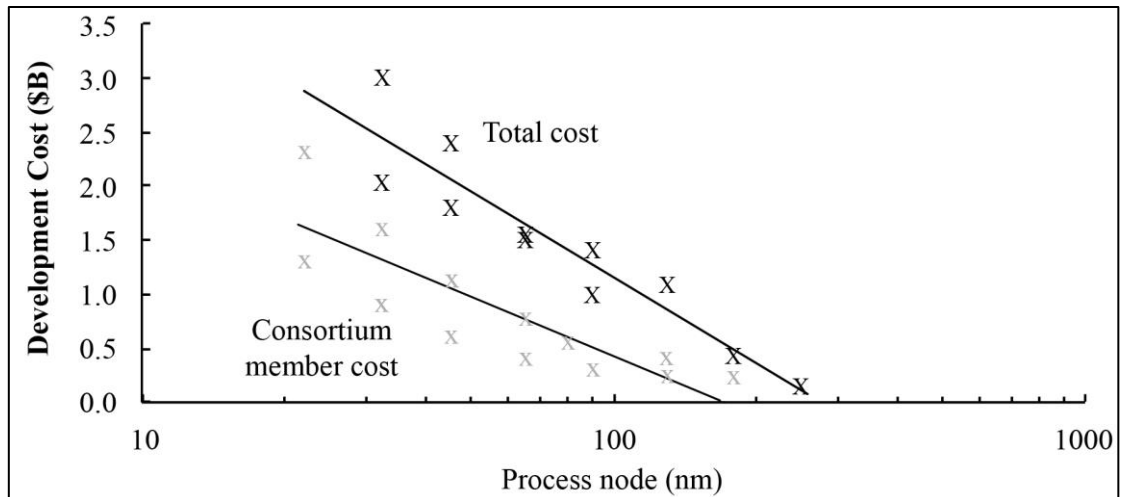


Figure 4.4: Process Development Cost Comparison
Source: IC Insights, 2014.

As discussed in the earlier chapter, the Common Platform Alliance was established by IBM and GlobalFoundries in 2002. Later, Samsung joined and the alliance was named the “Manufacturing Alliance Partners”. While TSMC did not participate in this alliance, Samsung and GlobalFoundry gained important advantages through this collaboration as the new collaborative-foundry model provides the firms the access to advanced CMOS process technology, an open design ecosystem and global sources of manufacturing to enhance capacity as compared to the traditional foundry models (Common Platform, 2013).

Together with STMicroelectronics, Infineon, Freescale, Renesas, and Toshiba, the three firms (i.e. IBM, GlobalFoundries and Samsung) formed “Joint Development Partners”. However, only STMicroelectronics has participated in the development of technologies beyond 28nm (Phase II). Table 4.3 shows the list of the alliance members which also consists of 16 Design Enablement Partners. The alliance shows that open innovation requires firms from different specialization to come together to ensure different knowledge is transferred and shared between upstream and downstream firms to ensure values are created for the value network as a whole. This alliance consists of more industry players, mostly technology followers in their respective specializations. The main objective is not to minimize the transaction cost, but to gain access to the external knowledge of different specialized firms. The end result is to develop the process technologies collectively so as to reduce their gaps with the technology leaders in their respective segments.

Table 4.3: Common Platform Partners

R&D Partnership	Participating firms
Manufacturing Alliance Partners	GlobalFoundries (2002), IBM (2002), Samsung (2004)
Joint Development Partners	GlobalFoundries (2002), IBM (2002), Samsung (2004), STMicroelectronics (2007) Infineon, Freescale, Renesas, and Toshiba have also been Joint Development Partners, but not for the advanced process nodes (i.e., <28nm)
Design Enablement Partners	Amkor Technology, Analog Bits, Apache Design Solutions, Aragio Solutions, ARM, Cadence Design Systems, ChipEstimate.com, Cosmic Curcuits, Infotech, Kilopass, Mentor Graphics, QuantumThink Group, Synopsys, True Circuits, Uniquify, VeriSilicon

Source: Common Platform, 2013; IC Insights, 2014.

(c) Organizational core competency

In Phase I, organizational core competency remains critical for leading firms whereas smaller competitors gather to collaborate in innovation. For instance, in 2000, UMC established R&D partnership with IBM and Germany's Infineon Technologies to develop 130nm and 100nm technologies. UMC reckoned that the increasing complexity and costs of relentless miniaturization made it impractical and difficult for any firm to independently commercialize the new process nodes. In contrast, TSMC had already begun R&D on those process nodes alone at that time. Historically, a number of IDMs have opened up their foundry facilities and offered foundry services to fill their capacity, including Texas Instruments, LSI Logic, and IBM. IBM was considered a major competitor to TSMC in the early 2000s, given its cutting edge technology, a dedicated 300mm platform and an extensive IP portfolio.

Following TSMC's strategy to internally develop the technologies, Figure 4.5 shows that the R&D expenditure between TSMC and UMC began to diverge since 2000 and continued to diverge dramatically in the following years. The result is a dramatic lead over its competitors in R&D output, including SMIC and Chartered Semiconductor which was not acquired by GlobalFoundries until 2010. Figure 4.6 shows that there is a

huge gap between the numbers of US patents granted to TSMC and UMC since the divergence of R&D expenditure. The IPs developed by TSMC are now offered as a suite of services to IDM and fabless customers to shorten the required period of time for design and pre-production phases of chip manufacturing.

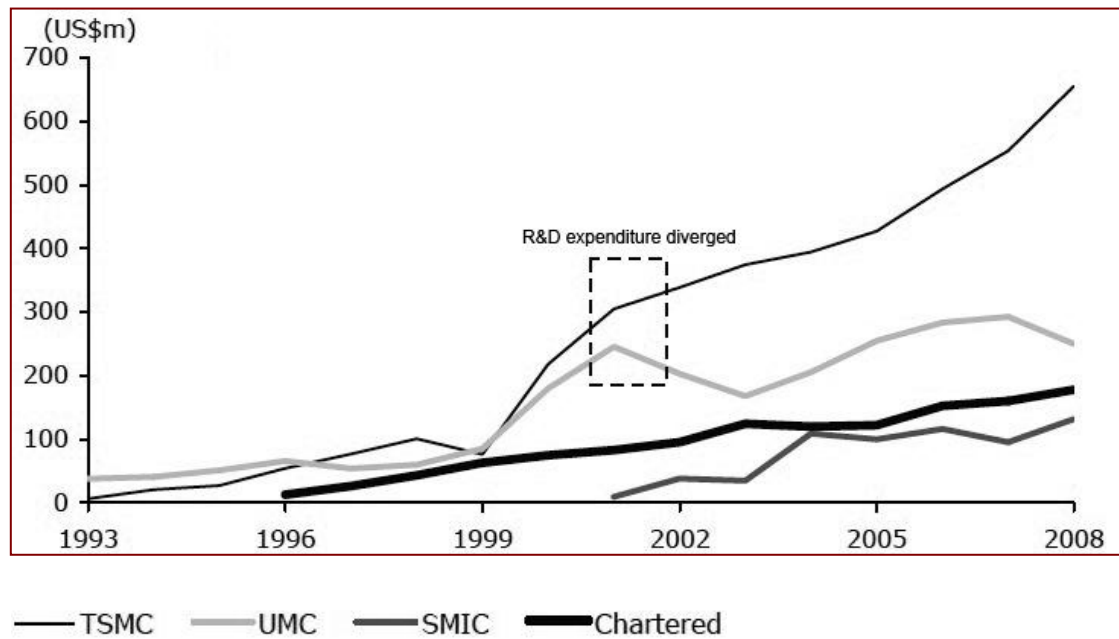


Figure 4.5: R&D Expenditure by Leading Pure-Play Foundries
Source: CLSA Research, 2012.

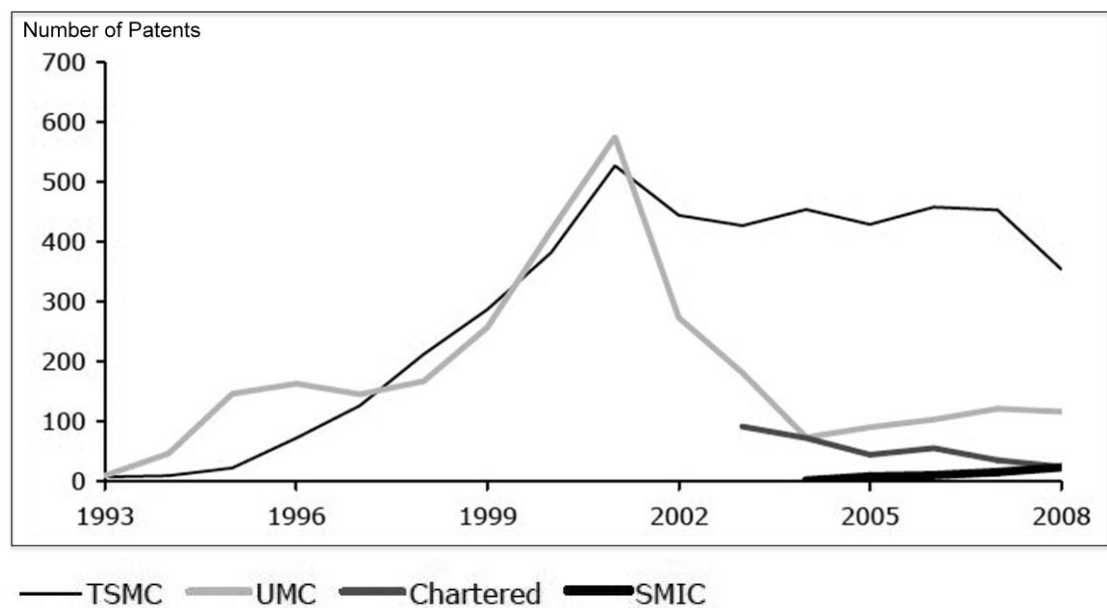


Figure 4.6: Number of US Patents Granted to Leading Pure-Play Foundries
Source: United States Patent and Trademark Office (USPTO), 2011; CLSA Research, 2012.

4.4.2 Phase II: Towards Virtual Vertical Integration

In Phase II, larger firms in the IC industry change their business model and the types of technologies they seek to build with the objective to achieve virtual vertical integration. This requires the firms to continue seeking and building stronger linkages within their value network, causing changes in the industry's value systems. In Phase II, it was found that the Taiwanese latecomers have moved into Dimension III(b) whereas the Malaysian latecomer firms have not moved beyond Dimension III(a). However, only TSMC has moved into Dimension IV(b).

4.4.2.1 Taiwanese Latecomers

In Phase II, the Taiwanese foundries have developed strong vertical integration through time. From a pure-play foundry merely fabricating wafers, TSMC and UMC have developed capabilities to participate in almost all the key production stages. The Taiwanese foundries have pursued both radical and incremental innovations. For instance, TSMC has pursued the miniaturization league of Moore's Law, as well as, More than Moore's Law (horizontal expansion). At the back-end operations, Taiwanese ASE has vertically expanded its scope of operations in a less intense manner, by collaborating closely with customers for vertical upgrading. The Taiwanese latecomers have also sought to expand their markets within their respective specialization by advancing into new process nodes.

(a) Virtual vertical integration by Taiwanese foundries

The typical stages of IC development are R&D, EDA technology kit, IP library, chip design, taping out and masking, wafer fabrication, wafer bumping, wafer sorting, packaging, and final testing. To pursue virtual vertical integration, TSMC has vertically upgraded into all these stages by participating in the activities partially or fully. The integrated services offered by TSMC are categorized into design infrastructure, mask

service, wafer fab service, assembly and testing, as well as, failure analysis and cybershuttle service. Figure 4.7 shows how the activities of a traditional IDM can now be segregated into different services offered by a foundry seeking to pursue virtual vertical integration. The examples of virtual vertical integration by the selected cases are presented in Figure 4.8. UMC as a follower has tried to pursue TSMC's strategy of virtual vertical integration. However, UMC has accumulated lower capabilities in all stages and participation beyond its specialization is limited.

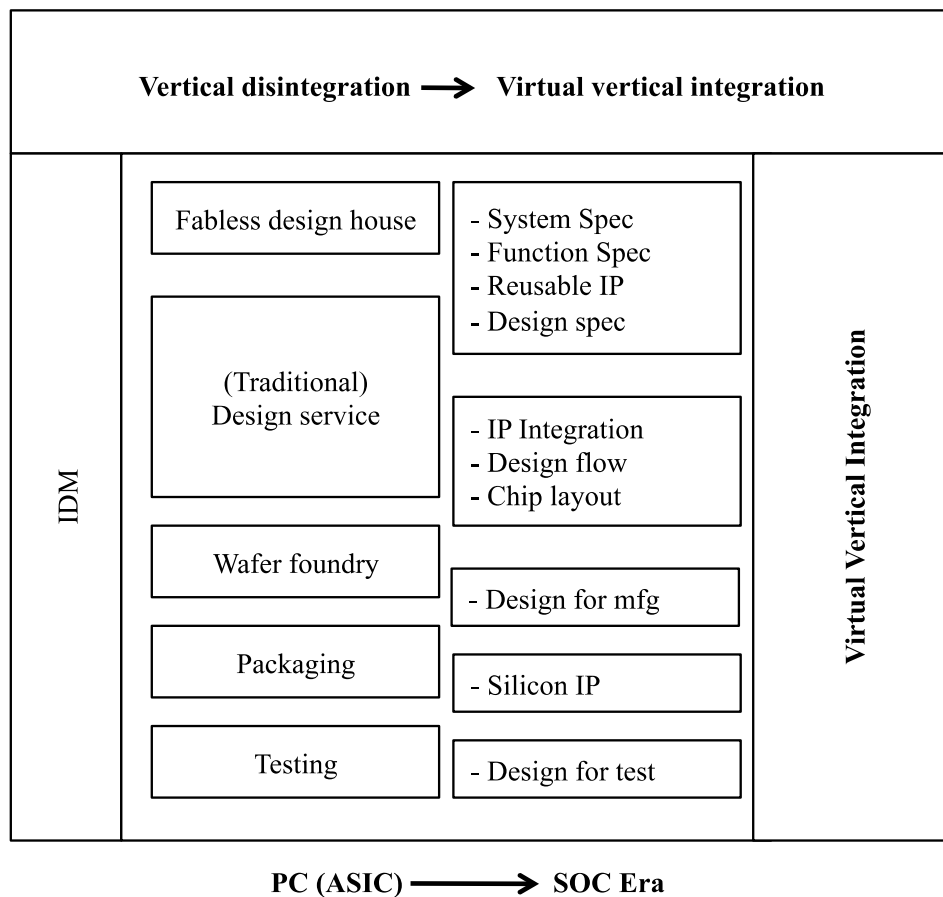


Figure 4.7: Segmentation of Foundry Sector
Source: CLSA Emerging Markets, 2005.

Global Unichip is a chip design firm founded in 1998 to provide application-specific integrated circuit (ASIC) design services, non-recurring engineering (NRE – one time design/ partial design fees), multi-project wafer services (MPW), and silicon IPs to fabless firms, IDMs and system houses. In 2003, TSMC invested in Global Unichip

(37% of ownership) and became the primary shareholder with the objective to speed up time-to-market and to solve design complexities and manufacturing integration issues. As part of its efforts to pursue virtual vertical integration, TSMC's ownership in Global Unichip enables the firm to integrate design and manufacturing at increasingly smaller and complex process nodes in Phase II. The foundry-design combination allows TSMC to provide complementary service offerings to its customers, and to ensure faster time-to-market and technology migration plans.

The design and pre-production costs per chip for new process nodes have been increasing. As of 2009, the total design and pre-production cost at the 65nm process node is US\$ 34million, more than 2.5 times the cost at the 180nm node (see Figure 4.9). At 65nm, the costs for photo-masking and testing have risen and account for 32% of total pre-production costs, as compared to 19% at the 180nm process node (see Figure 4.10). To create additional values for its customers, TSMC has vertically integrated into this segment. By combining its photo-masking and testing facilities, TSMC is able to shorten the time-to-market for new designs and to reduce cost for its customers.

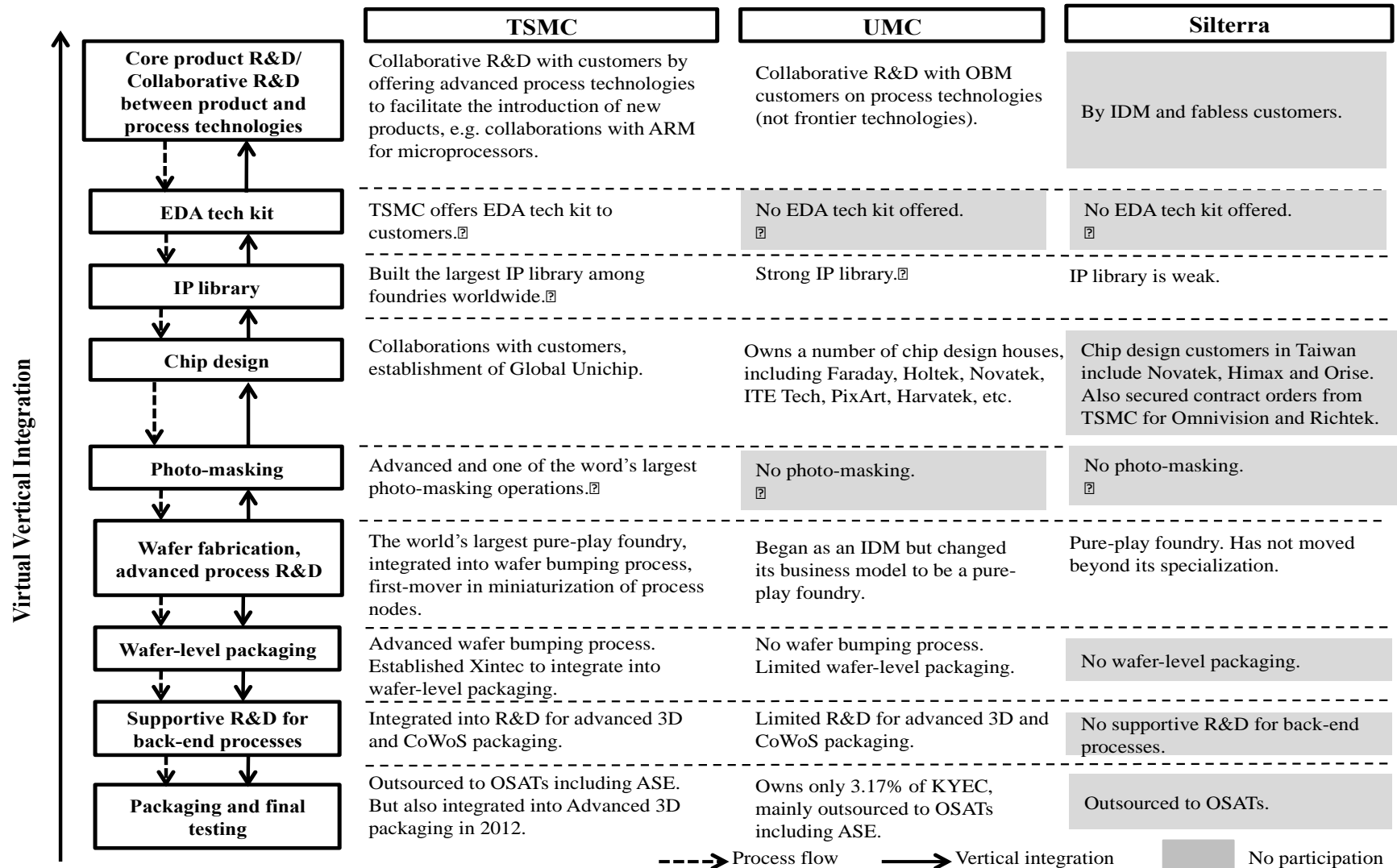


Figure 4.8: Virtual Vertical Integration by Advanced Pure-Play Foundries
Source: Interview findings, 2012-2013.

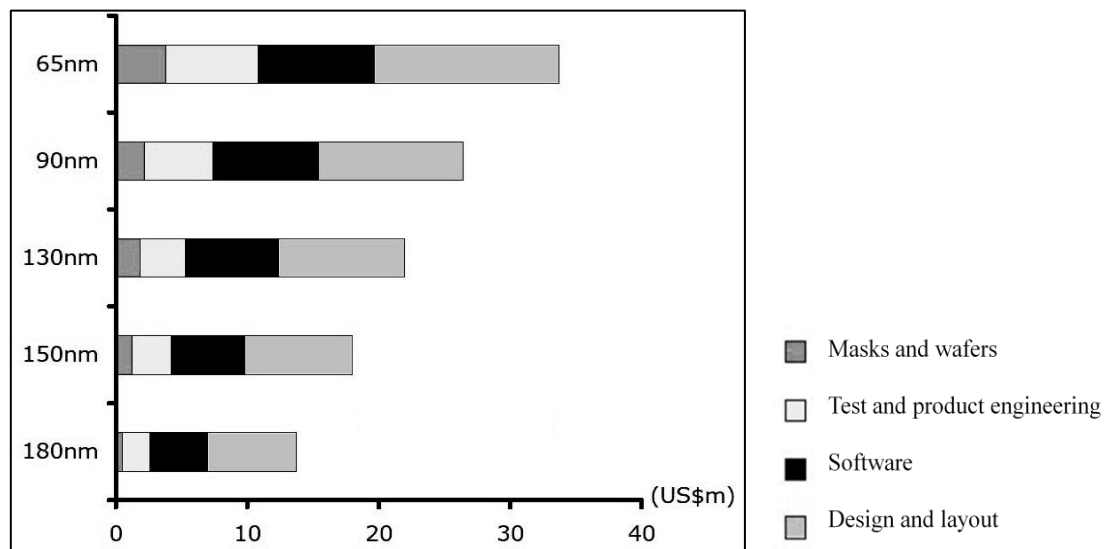


Figure 4.9: Design and Pre-Production Costs
Source: CLSA Research, 2012.

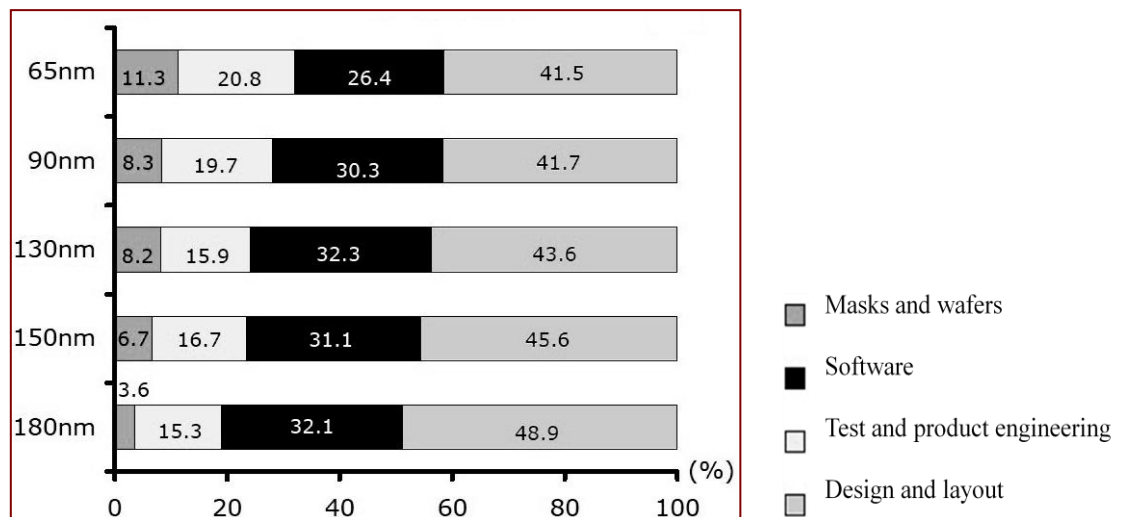


Figure 4.10: Costs of Photo-Masking and Testing (%)
Source: CLSA Research, 2012.

TSMC has one of the world's most advanced photo-masking technologies in Phase II, whereas UMC has not participated in photo-masking activities. A mask is a glass plate covered with patterns that represent the negative copy of etching for a wafer. The pattern is passed onto each silicon wafer in the lithography process (CLSA Research, 2012). To create extra values for its customers, TSMC's mask services are connected with its manufacturing through a computer-integrated manufacturing (CIM) system. TSMC also has an online database (TSMC-Online) where information about mask

designs is accessible. This allows high accuracy of the manufacturing process, with very fast turnaround time for customers (CLSA Research, 2012).

TSMC is not only participating in the photo-masking process but also seeking to advance the frontier of the respective technology. In Phase II, process miniaturization has resulted in more densely crammed chips requiring increasingly finer etching designs, which has caused issues in the lithography process. Manufacturers often struggled with etching precision due to the extremely fine nature of the etching designs. TSMC introduced a process called optical proximity correction (OPC) to solve the lithographic issue. This technology is able to anticipate the irregularities of shape and size and to correct the photo-mask images. It then produces a light beam that more precisely approximates the intended shapes. This new process introduced by TSMC has facilitated faster design changes, which has been critical in the progress of the IC industry.

UMC has tried to follow TSMC's strategy for virtual vertical integration, although the vertical scope of its activities has not been as comprehensive as TSMC's. UMC has a strong IP library (more details will be discussed later) and the foundry has invested in a number of fabless firms. The list of UMC-related fabless firms includes Novatek (10.6% ownership), PixArt (12.4% ownership), Holtek (16.4% ownership), SiS (16.4% ownership) and Faraday (15.9%). Most of the chips fabricated in UMC are shipped to OSATs for backend packaging and testing. UMC only has 3.17% of ownership in an OSAT firm – KYEC. Although these subsidiaries are not consolidated into UMC's main operations, they nevertheless provide UMC some access to knowledge in these respective areas.

(b) Vertical upgrading by Taiwanese OSAT

ASE has remained dedicated to the R&D of new material technologies, such as, copper wire bonding, flip-chip and copper pillar bumping. Figure 4.11 shows that its capital expenditure and R&D spending accounted for 40% and 58% respectively of the world's top-four OSATs (i.e. ASE, Amkor, SPIL and STATS ChipPAC) in 2010.

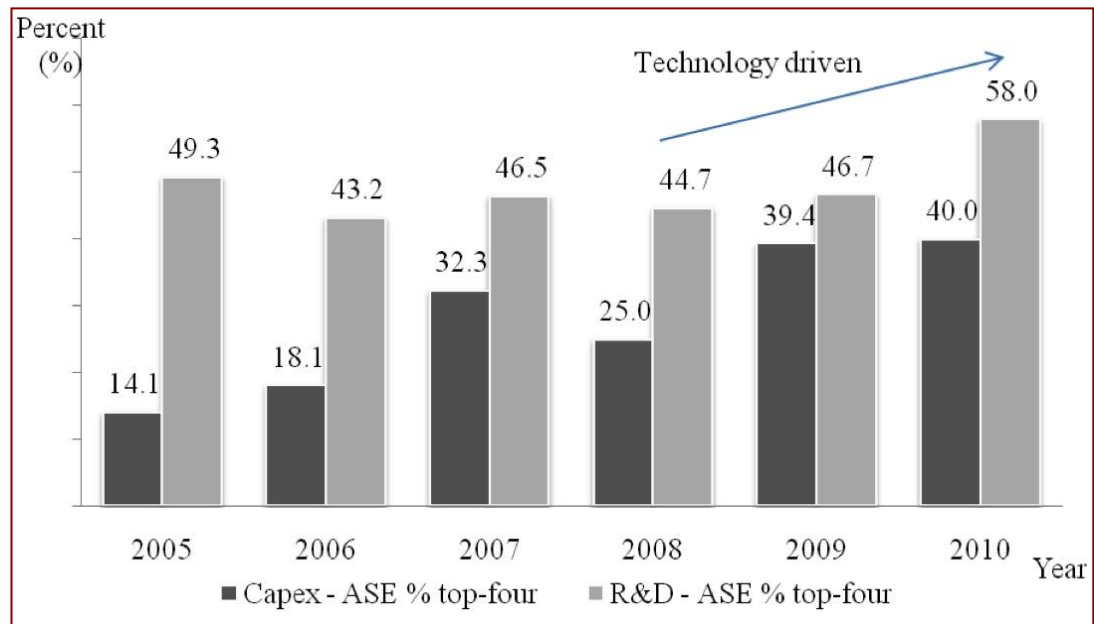


Figure 4.11: Share of ASE Capital and R&D Expenditure among World's Top-Four OSATs, 2005-2010 (%)

Source: Credit Suisse (2012); Gartner (2013)

With the advancement of packaging technology, the need for stronger integration within the IC supply chain has increased. As the required knowledge and skills for back-end manufacturing have extended to wafer processing and substrate areas, higher values flow to the mid-end processes. Although an advanced foundry like TSMC is vertically integrating as it can increase its wafer bumping capacity and undertake packaging in-house so that these activities are technologically in sync with node miniaturization, advanced OSAT firms like ASE also conduct R&D on 3D packaging to integrate the new technologies into its chip packages. Advanced packaging technologies like 'wafer-level packaging' (WLP) and 'through-silicon-via' (TSV), which utilize specialized

wafer-foundry knowledge such as wafer bumping and wafer drilling, induce foundries and OSATs to integrate into the mid-end stages in the IC value chain. TSMC and ASE were the only foundry and OSAT equipped with the technological capabilities to participate in these activities as of 2012.

R&D-driven foundries like TSMC also capture mid-end manufacturing opportunities due to their know-how of wafer-level technologies. OSATs like ASE require high technological capabilities to compete with foundries whereas smaller OSATs are largely disadvantaged. Meanwhile, embedded die packaging, where know-how pertaining to substrate features (such as circuit distribution and cavity techniques) is critical, has increased the value-add of substrate suppliers (CLSA Research, 2012). OSAT players with close cooperation or vertical integration into these activities enjoy a competitive advantage over the others. Besides a series of aggressive mergers and acquisitions, ASE also integrated ASE Chung Li and ASE Material in 2003. ASE Material has become an integral part of ASE's business model, as the value-addition of chip packaging is migrating towards chip substrates.

As the industry's most advanced OSAT, ASE established strong collaborations with upstream customers and has been able to capture a large share of the value that flows towards the mid-end manufacturing segment. On top of that, the firm has advantages over its competitors in the advanced back-end segment, such as 3D packaging, since the firm has accumulated deep knowledge of wafer sorting and packaging processes. Although its largest competitor - Amkor Technology – tried to integrate into the foundry business in the late 1990s, ASE remains focused as a back-end contract manufacturer, without trespassing into foundries' specialization. ASE also built a more comprehensive list of packaging technologies as compared to smaller OSATs like Globetronics and Inari (Appendix A).

4.4.2.2 Limited Vertical Upgrading by Malaysian Latecomers

As compared to advanced foundries, Silterra has not expanded its vertical chain of operations. The latecomer firm has not moved beyond Dimension I in the proposed framework. Its activities are mainly confined within the original specialization, with a fair amount of IP collections. By 2006, Silterra was the second largest wafer fabrication house in Southeast Asia. While industry leaders like TSMC, Samsung and Global Foundries invested incessantly in the development of 32 and 28nanometer (nm) technology in 2010, Silterra was mainly targeting the “sweet spots” of the market by producing chips at 180nm-110nm. As a latecomer, Silterra carefully strategized the types of technology to be built in Phase II in order to secure its position in the GVC under intense competition. The most popular nodes for 200 mm wafer foundries in 2010 were 180 nm and 130 nm. In fact, Silterra mainly pursued More than Moore’s Law, which was to add functional features to each existing node instead of participating in the miniaturization race.

Silterra has a joint technology development project with ProMos Technologies (Taiwan). While Silterra transferred its 0.13-micron and 0.11-micron High-Voltage (HV) process technology for small-panel LCD driver IC applications to ProMOS, ProMOS opened up its wafer fab in Taichung, Taiwan for Silterra and provided technological support for 12” fabrication facilities. Through this collaboration, technology transfer took place between the two firms and both are able to share the pie of the fast growing smart phone market. However, such collaboration does not involve knowledge exchange between upstream and downstream firms. Instead, the two foundries collaborated based on reasoning related to transaction cost, combined capacity and scale, as well as, market gains.

The Malaysian owned Globetronics and Inari Amertron also made great efforts to insert themselves into more stages in the global value chain. Globetronics expanded into new product and process technology segments, including from burn-in services to plastic package assembly, to ceramics assembly, to module assembly, to customized LED and to sensor packages. Also, the firm expanded from memory devices to transistor products, to IC, to LED products, to timing devices, to sensors (see Table 4.4). In terms of consumer electronics products, the firm expanded from customized products to smart phones, to LED lighting products. Globetronics also collaborates with its supply chain partners to develop new material and processes.

Inari Amertron carried out a series of business expansions and acquisitions. CEEDTec Sdn Bhd is a 51% own subsidiary of Inari acquired in January 2012 with Agilent Technologies being the major customer. Inari South Keytech Sdn Bhd (ISK), incorporated in June 2012, is a fiber-optic division supplies mainly to Avago. The key activities conducted by Inari Amertron as an OSAT include direct current and RF wafer testing, wafer back-grinding, wafer sawing, wire bonding, substrate molding and substrate sawing (see Figure 4.3). In 2013, the company decided to upgrade its process technology to include advanced packaging in the form of fine pitch flip-chip IC since the market growth of wireless devices and smart devices has increased the demand for RF flip chip IC.

Inari Amertron has also become the first in the industry to introduce the ‘back-end laser marking’ at wafer-level process and the first to introduce the ‘3D solder paste inspection’ process in semiconductor manufacturing. The company’s technical personnel are sent to Singapore for training programs for technology transfer from Avago. Inari Technology, a subsidiary of the group, has also collaborated with a local automation manufacturer – ViTrox Technologies to develop ViTrox’s machines to conduct ‘3D X-ray Inspection’. This new development opened up windows of opportunity for ViTrox to enter 3D X-ray

– a segment that ViTrox has not explored before. The technological deepening efforts by Inari Amertron also enable the collaborative partner to manufacture high-end products to export to the global market. It allows the firm to compete globally. Inari Amertron Group products are used in a variety of high-technology wireless telecommunications products such as smartphones, tablet computers, and wireless modems; optoelectronics, sensors, and fibre optics.

Nevertheless, Globetronics and Inari have limited vertical upgrading and their catch-ups have not progressed beyond Dimension III(a). Both of the firms do not own an IP library. Nevertheless, through collaborations with customers, they are able to participate in their customers' chip designing process by providing quick prototyping or New Product Introductions (NPIs) for testing. For instance, Globetronics provides NPIs to customers such as EPSON, Avago and Heptagon whereas Inari provides NPIs to Avago, OSRAM and Agilent. The examples of vertical upgrading by OSAT firms are summarized in Figure 4.12. Meanwhile, the findings of organizational business models and resource acquisitions strategies are summarized in Table 4.4.

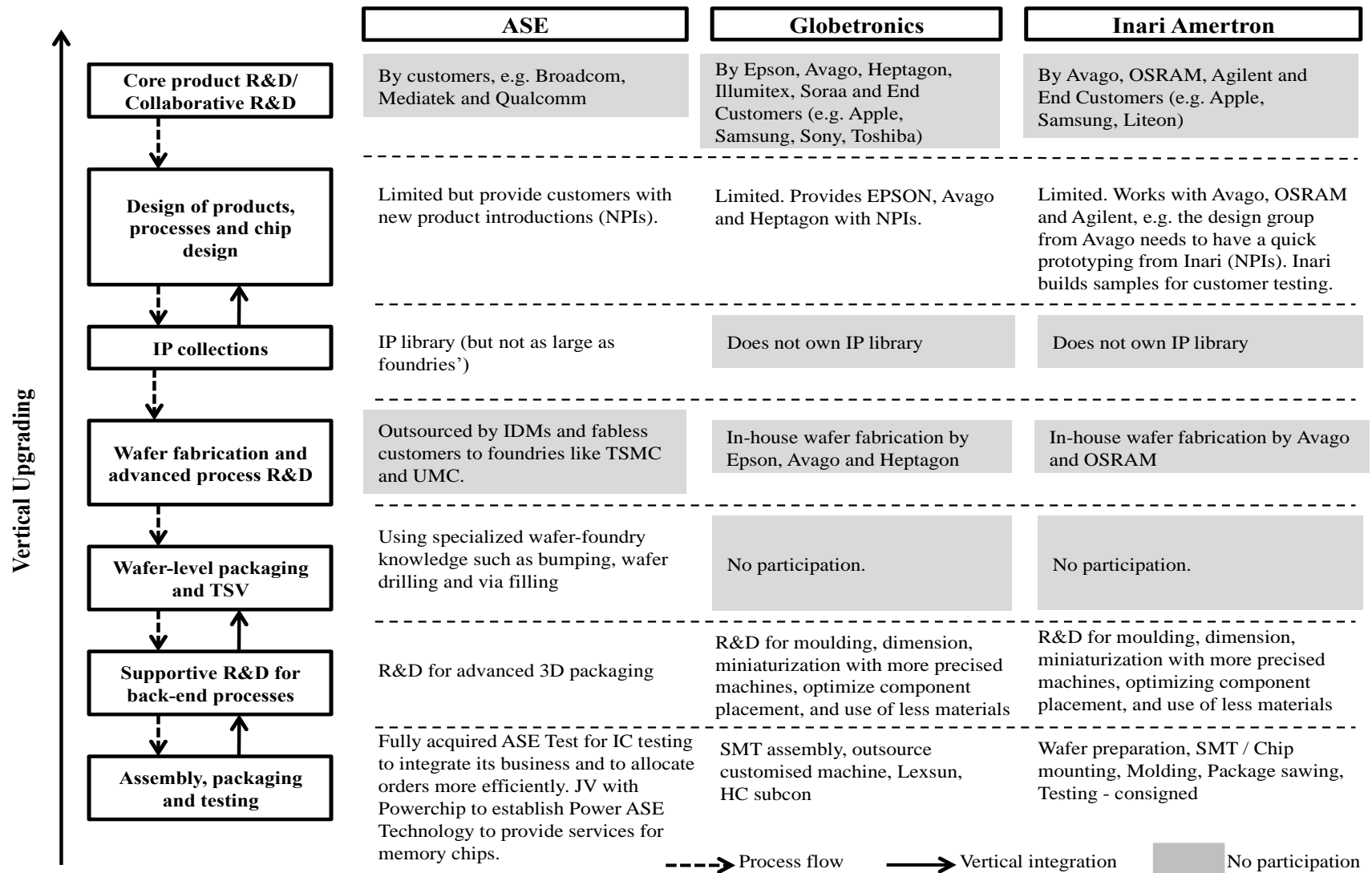


Figure 4.12: Vertical Upgrading of Back-End Manufacturing Firms
Source: Interview findings, 2012-2013.

Table 4.4: Phase II – Catching up in the Context of Virtual Vertical Integration

Phase II Towards Virtual Vertical Integration (VVI)		Taiwan			Malaysia		
		Front-end		Back-end	Front-end	Back-end	
		TSMC Dimension IV(b)	UMC Dimension III(b)	ASE Dimension III(b)	Silterra Dimension I	Globetronics Dimension III(a)	Inari Amertron Dimension III(a)
Year		~2008 onwards					
Business model	Contract manufacturer	Pure-play foundry, one-stop center	Pure-play foundry	OSAT	Pure-play foundry	OSAT	OSAT
	Production specialization	Front-end wafer fabrication, virtual vertical integration	Front-end wafer fabrication, limited virtual vertical integration	Back-end packaging and testing, backward and forward integration	Front-end wafer fabrication	Back-end packaging and testing	Back-end packaging and testing, forward integration
	Targeted customers	Fabless firms, chip design houses, IDMs, systems integration firms	Fabless firms, chip design houses, IDMs, systems integration firms	Fabless firms, IDMs, systems integration firms	Fabless firms, IDMs, systems integration firms	IDMs, systems integration firms	Systems integration firms, IDMs like Avago Technologies
	End-consumer market	Various, production ranges from logic ICs to microprocessors	Various	Various	Focused, niche. Smart phones, mobile products, wireless products	Focused, niche. Quartz and timing devices, LEDs, sensors in mobiles	Focused, niche. Fine Pitch flip-chip. Wireless telco products.
Resource acquisitions (Technologies developed)	Rareness (How new is technological development)	First-mover (process node miniaturization)	Fast-follower (second-mover in process node miniaturization)	Fast-follower of foundries; first-mover among OSATs	Mainstream (the most common process nodes). 'Sweet spots' of the market.	Mainstream (continuous use of more obsolete technology)	Mainstream (invests in popular technologies and outsources obsolete production)
	Imitability	Less imitable	Less imitable	Less imitable	Imitable	Imitable	Imitable
	Transferability	Less transferable	Less transferable	Less transferable	Transferable	Transferable	Transferable
	Substitutability	No (Highly risky)	Refer to first-mover (less risky)	Yes	Yes	Yes	Yes
	Maturity (Life cycle)	Emerging/introduction	Growing	Growing	Mature	Mature	Emerging (RF flip-chip)
	Competitiveness	'Co-opetition' with partners at the frontier technology	Competitive among other leading foundries	Major incumbents exist	Competitive among smaller foundries	Competitive (price cut, etc.)	Competitive (Low technological entry barrier)

Source: Authors' elaborations based on interview findings, 2012-2013

4.4.2.3 Changing Value Systems

In Phase II, there are increasing open innovations among smaller firms in the industry to gather resources and knowledge in order to keep up with the rapid technological progress. Open innovations take place between smaller firms and their peers, as well as, between upstream and downstream firms. Leading firms also participate in open innovations that facilitate them to vertically integrate the scope of activities. Moreover, leading firms in the industry form consortiums among themselves and participate in alliances to solve technical issues and to push the frontier of technologies. The collective vision is to create values for each participant within a particular value network and to maintain a wide technological gap between themselves and smaller firms.

The formation of virtual vertical integration among leading firms has led to industry concentration, especially towards the later part of Phase II. In time, latecomers that deploy this strategy can seek to close the gap with frontier IDMs, despite being contract manufacturers. However, not every latecomer can achieve this. Among the selected cases for this study, TSMC's catch-up experience has demonstrated this process. Smaller firms that are not able to progress into Dimension III (b) remain adding values step by step to the vertical chain of production. Despite increasing open innovations, core competency remains important to leading firms like TSMC, since its main value creation for customers is offering advanced process technologies for wafer fabrication. Moreover, there is competition among the leading firms in the respective collaborations.

(a) Stronger ties between upstream and downstream firms

Advanced firms in the industry have also participated in open research institutes or collaborative organizations to gain access to external knowledge. Important examples of open research institutes include IMEC, SEMATECH, Selete in Japan (part of AIST

National Institute), the University at Albany's Center for Semiconductor Research in New York, the Semiconductor Research Corporation (SRC) with its Global Research Collaboration, Focus Center Research Program, and the Nanoelectronics Research Initiative (IC Insights, 2014). These open innovation platforms have enabled participants to discover, select and develop new IC technologies.

Figure 4.13 shows another critical example of an open innovation platform. Although IMEC was founded in 1984, the research institute gained increasing prominence since Phase II. As of 2013, IMEC is one of the world's largest groups of firms collaborating in semiconductor R&D. As shown in Figure 4.13, IMEC semiconductor R&D partnership ecosystem consists of upstream and downstream firms specializing in different expertise, including 17 of the industry's most prominent IDMs, pure-play foundries, and fabless and fab-lite suppliers. In addition, other semiconductor firms participating in this R&D ecosystem include approximately 80 leading suppliers of materials, equipment, chip design tools and services, and device assembly and test services (IC Insights, 2014). TSMC, Samsung and GlobalFoundries are the only foundries participating in this open platform.

The ecosystem has enabled the foundries to acquire IC designing knowledge from leading fabless firms, including Qualcomm, Xilinx, Nvidia and Altera. The prominent IDMs that are willing to share relevant knowledge in this research platform include Intel, Panasonic, Samsung, Micron, SK Hynix, Toshiba and ON Semiconductor. However, the increasing technological interrelatedness between IC upstream and downstream firms has resulted in the need for material and equipment suppliers to also participate with the IC firms in order to drive technological development. This ecosystem has connected relatively larger firms to come together, despite specializing in different segments of the industry.

System Manufacturers (about 30 system manufacturers)	
Logic, Memory, Power Device IDMs (Intel, Panasonic, Samsung, Micron, SK Hynix, Toshiba/SanDisk ON)	Fabless Suppliers (Qualcomm, Xilinx, Nvidia, Altera)
	Fablite Suppliers (Sony, Fujitsu, NXP)
	Foundries (TSMC, Samsung, GlobalFoundries)
Suppliers (about 80 equipment and material suppliers, EDA vendors, and assembly & test companies)	
Material Suppliers	Equipment Suppliers
EDA	Packaging and Test

Figure 4.13: Integrated Semiconductor R&D Ecosystem in IMEC
Source: IMEC, 2012, IC Insights, 2014.

(b) Collaborations to push technological frontier

In Phase II, although TSMC's logic chip fabrication remains its core competency, the foundry has also integrated into frontier technology of semiconductor equipment as part of its effort to pursue virtual vertical integration. One of the most important and costly pieces of equipment that contributes to the rising cost of new fabs is the lithography system. Figure 4.14 shows the rising cost of the critical exposure system as the industry migrates to bigger wafer sizes in tandem with smaller process linewidth. Towards the late 2000s, the latest lithography systems for 450 mm-wafer manufacturing are estimated to cost more than \$ 125 million for each tool. However, a number of challenges need to overcome in order to commercialize the Extreme Ultraviolet (EUV) systems. For instance, firms face increasing difficulty to decrease mask defect densities and improve system throughput.

To push the technology frontier of the new generation of EUV systems to achieve 126 wafers per hour, leading IC foundries in the industry have come together to cooperate to develop the required masks and resist materials. On top of that, IC manufacturers also

collaborate and work closely with equipment makers to push the technology frontier and maximize the usage of the equipment. The collective outcomes including improved optics and enhanced illumination technologies have allowed manufacturers to extend the life of 248nm KrF laser technology so that it can be used to produce non-critical layers of 22/20nm-generation ICs (IC Insights, 2014). Moreover, collaborations among IC manufacturers and equipment makers have also led to improvements in throughput rates that have mitigated the increasing costs of lithography.

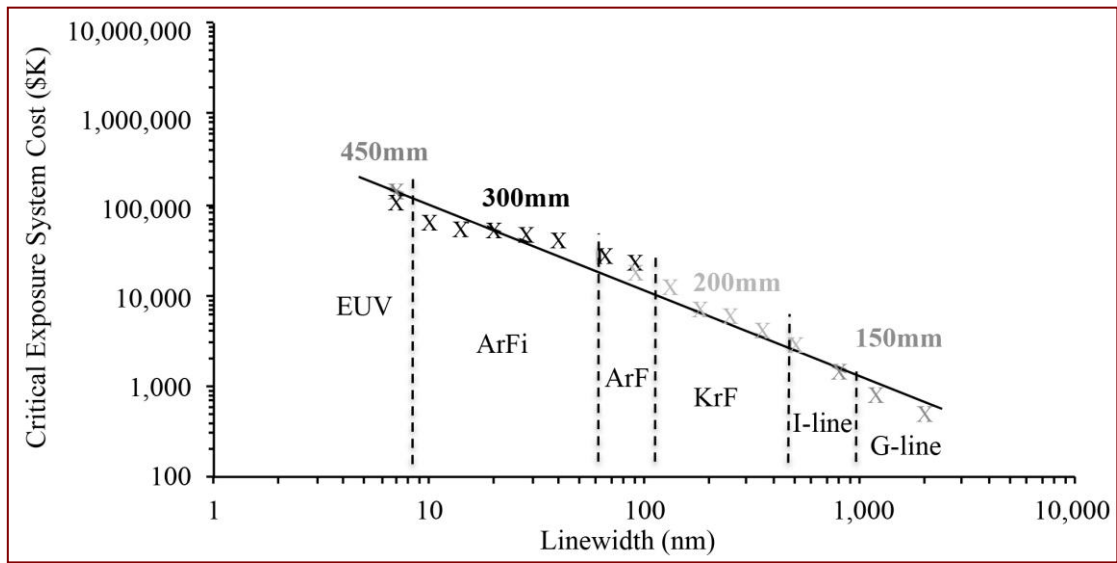


Figure 4.14: Critical Exposure System Cost Trend
Source: IC Insights, 2014.

Table 4.5 shows the co-invested R&D between the three largest IC foundries and the world's largest IC equipment maker – ASML – to develop the latest EUV technology system for 450mm manufacturing. In July 2012, Intel announced it would allocate \$ 1 billion over the next five years to conduct R&D with ASML to accelerate development (IC Insights, 2014). In August 2012, TSMC announced it would allocate approximately \$ 1 billion to join the cooperative program and gain 5% ownership of ASML. Meanwhile, TSMC also allocated approximately US\$ 337 million for the R&D for four years (2013 – 2017) whereas Samsung decided to invest US\$ 330 million into the R&D.

Collectively, Intel, TSMC and Samsung account for 23% of ASML. This collaboration only consists of leading large firms, of which the objective of TSMC is to push the technology frontier of IC equipment makers and to further widen its gaps with competitors lagging in technology.

Table 4.5 ASML's Co-Investment Program for EUV and 450mm Technology Migration

Company	Equity Investment (USD billion)	Ownership (Percentage %)	R&D Investment (2013-2017) (USD billion)
Intel	2.98	15	0.99
TSMC	1	5	0.33
Samsung	0.6	3	0.33
Total	4.58	23	1.65

Source: ASML, 2012.

(c) Value creation and value capture

By participating in various IP alliances, TSMC collaborated closely with selected alliance members to implement TSMC's design. These alliances include the IP Library Alliance, the EDA Alliance, and the Design Center Alliance. The Design Center Alliance is a network of worldwide experienced, qualified IC design centers. It combines technological capabilities and capacity to reduce significantly the risks of designing, manufacturing and time-to-market for customers.

Another important example of collaborations is IP sharing between TSMC and the firm's IP partners. "Quickstart" is a free IP prototyping programme introduced by TSMC. The objective of this programme is to accelerate chip prototyping to production and to shorten design cycle time (CLSA Research, 2012). TSMC and its IP partners (e.g. Cadence Design Systems, Mentor Graphics, and Barcelona Design) supply a pool of free IPs to the IP portfolio in this programme. Qualified customers are not required to pay licensing fees to IP providers until the production of their designs begin. Hence,

customers are allowed to receive prototypes at no cost and the development risk is greatly reduced. These collaborations create additional benefits for the foundry, the customers and the IP partners; each participant within the value network captures part of the collective values.

Through collaboration with EDA and other design infrastructure partners, TSMC has developed the UDFM to provide unified access to TSMC's foundry data (CLSA Research, 2012). As customers are provided with an exact copy of TSMC's factory tool chain and process models, the process makes the increasing manufacturing variances in advanced process technologies easier to be managed. Customers can improve design alignment between simulated hotspots and actual manufacturing hotspots easily, which ensure higher accuracy. This is another critical value created by TSMC to its customers.

In Phase II, foundries that are not able to move into Dimension III(b) find increasing difficulty to keep up with leading foundries. This is because more services are required by the designing firms to integrate a design with a process. As the design complexities increase, foundries are increasingly expected to provide assistance with SoC integration and IP services. Foundries that pursue the virtual vertical integration model participate in different segmentations of the foundry sector (see Figure 4.15). A full service foundry that participates in different segments also means that the foundry has to work closely with its partners, especially the upstream designing firms. The full-service foundry will have higher process expertise that distinguishes itself from other foundries, creating higher values to its networked partners and capturing higher values in return.

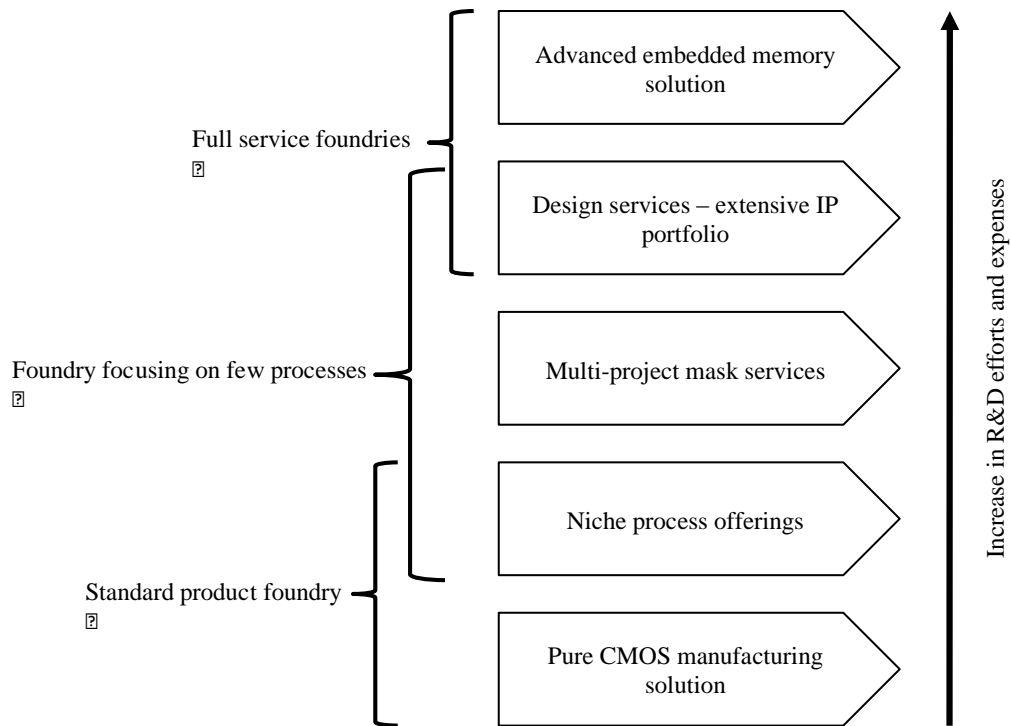


Figure 4.15: Segmentation of Foundry Sector

Source: CLSA Emerging Markets, 2005.

(d) Collaborations for technology migration

IC firms have also participated in research activities conducted at the CNSE's Albany NanoTech Complex, University of Albany. Research includes nanoscale lithography, nanoelectronic materials, and advanced interconnects. SEMATECH has moved its headquarters and almost all of its activities to the NanoTech complex and Albany since 2007. Table 4.6 shows the facilities built in CNSE's Albany NanoTech Complex. The facility houses vertically integrated R&D, prototyping, and educational activities. It provides strategic support to facilitate technology acceleration, business incubation, pilot prototyping, test-based integration, and other "next generation" nanotechnology research activities for the participant firms (CNSE, 2012). There are more than 300 global corporate partners, including Applied Materials, ASML, GlobalFoundries, IBM, Intel, Samsung, Toshiba and TSMC. Large-scale and capital intensive facilities were

aggressively built towards the end of Phase II, when new practice of open innovation began to gain prominence. The NanoFab Xtension was completed in 2013 with the objective to house the Global 450mm Consortium. However, as discussed in the earlier, only four IC firms have sufficient knowledge and resources to become early adopters of 450mm fabrication, namely Intel, Samsung, TSMC and GlobalFoundries (IC Insights, 2014). Other technology followers are facing difficulties to conduct the required R&D for 450mm wafers.

Table 4.6: CNSE's Albany NanoTech Complex

Facility	Year of completion	Investment (US\$ million)	Technological Development
NanoFab Xtension (or "West")	2013	365	<ul style="list-style-type: none"> - 450mm wafer fabrication and other next-generation technologies - Houses the Global 450mm Consortium
NanoFab Central and NanoFab East	March 2009	150	<ul style="list-style-type: none"> - 300mm wafer fabrication technologies
NanoFab North	December 2005	225	<ul style="list-style-type: none"> - 300mm wafer fabrication technologies - Houses the world's first EUV Alpha Demo tool
NanoFab South	March 2004	50	<ul style="list-style-type: none"> - Cleanroom space, classroom and office building
NanoFab 200 (also known as CESTM)	June 1997	16.5	<ul style="list-style-type: none"> - Cleanroom space, R&D laboratory, classroom, and office building

Source: CNSE, 2012; IC Insights, 2014

While the technology leaders are collaborating to push the technology frontier of production wafer size, technology followers in the industry are also collaborating to share the knowledge of 300mm wafer technology. One of the most important platforms is the CNSE's Albany NanoTech Complex, which also houses NanoFab Central (completed in 2009), Nanofab East (completed in 2009), and NanoFab North (completed in 2005).

(e) Industry concentration

Technological changes in the IC industry have also reversed the industry's value system from decentralization to industry concentration. Towards the end of Phase II as advanced firms form virtual vertical integration with upstream and downstream firms, the IC industry became highly concentrated in capacity, capital expenditure and revenues. Figure 4.16 shows that the revenue per wafer for 300mm production coupled with smaller technology nodes is stunningly higher than that for 200mm production with larger process nodes. However, only 36% of the firms that operate a 200mm wafer fab have upgraded to a 300mm wafer fab (IC Insights, 2014). As Figure 4.17 presents, the top five leaders in the IC industry account for 67% of the world's 300mm wafer capacity as of 2013. The second top five firms account for only 23%, followed by the third tier of firms (the third top five firms) which only accounted for an additional 6%. Only 4% of the values of 300mm manufacturing are captured by small and fragmented foundries in the industry.

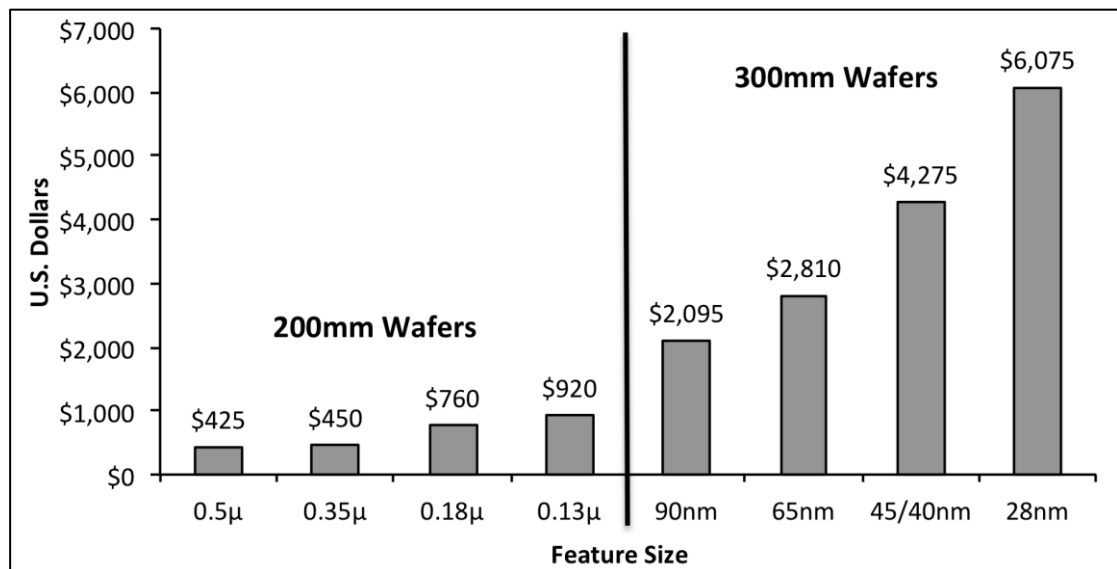


Figure 4.16: Typical Pure-Play Foundry Revenue per Logic Wafer in 2013
Source: IC Insights, 2014.

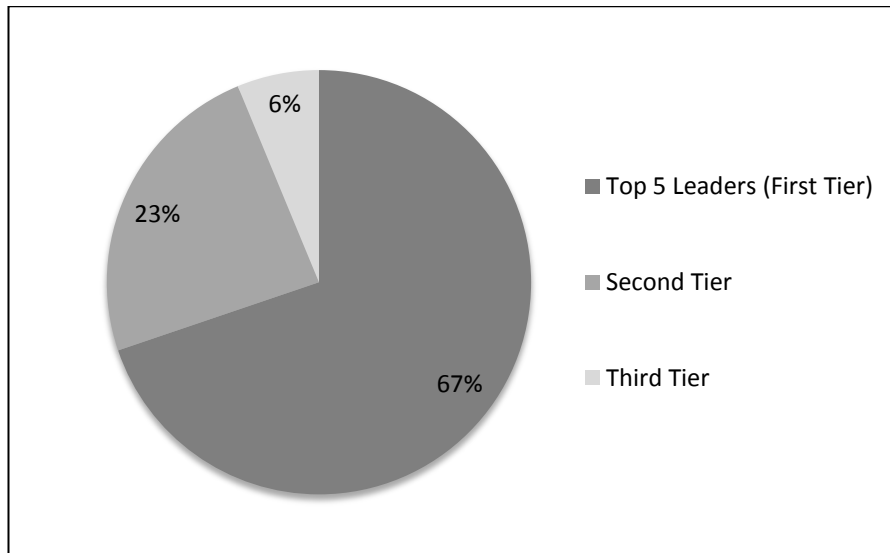


Figure 4.17: Worldwide 300mm Wafer Capacity of Industry Leaders, 2013 (%)
Source: Gartner, 2013; IC Insights, 2014.

Towards the end of Phase I (year 2005), the top five leaders in the IC industry accounted for 40% of the industry's total capital expenditure. Whereas the second tier firms (the second top five firms) made up for 15%, the third tier firms made up for only 12% (see Figure 4.18). In 2011, TSMC alone accounted for 49% of the foundry market share (see Figure 4.19). The segment for OSAT services also became concentrated in Phase II, with the two largest service providers accounting for almost 50% of the industry's market share in 2013 (see Figure 4.20).

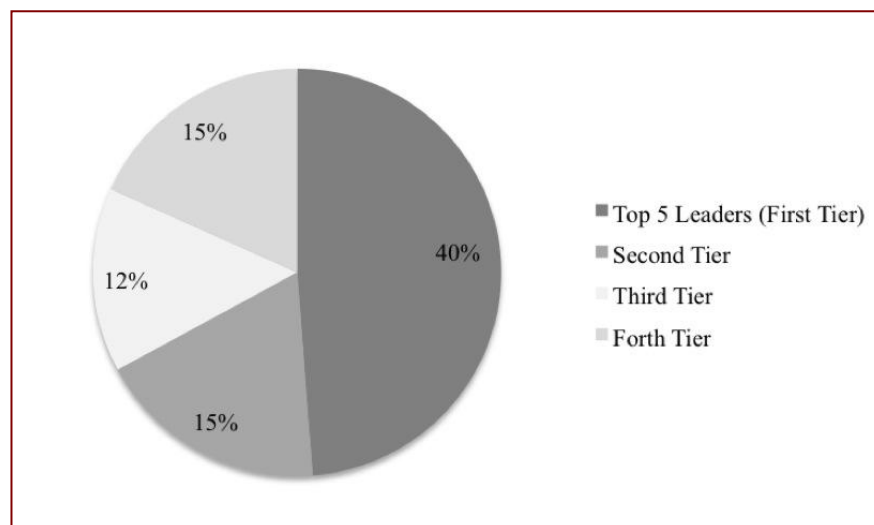


Figure 4.18: Worldwide Capital Expenditure, IC Industry, 2005 (%)
Source: IC Insights, 2012.

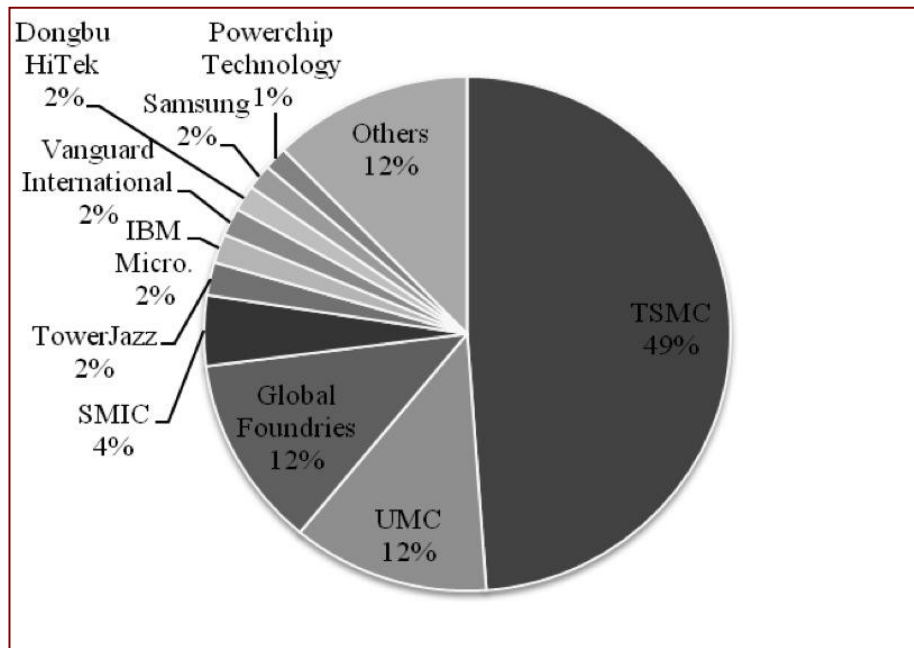


Figure 4.19: Foundry Market Share Breakdown by Revenue, 2011 (%)
Source: Gartner, 2013.

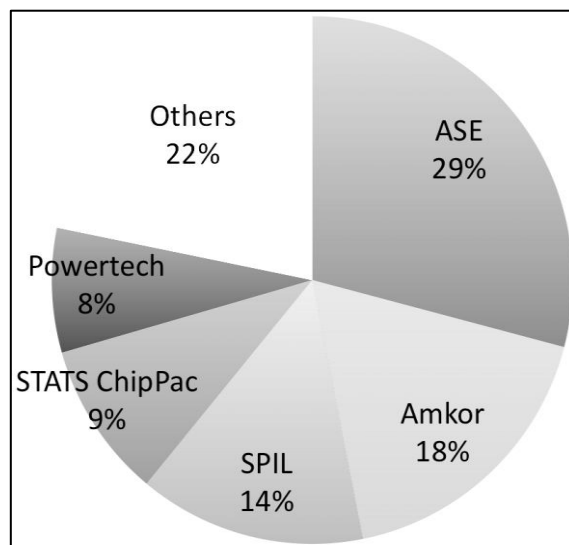


Figure 4.20: Top 10 OSAT Firms, 2013 (%)
Source: IC Insights, 2014

(f) Closing the gap with frontier IDMs

In Phase II, TSMC has progressed into Dimension IV (b) by reducing its technological gap with the world's leading IDMs. Figure 4.21 shows the time gap between TSMC and Intel and Samsung. In logic ICs, Samsung lagged TSMC by more than one year at 90nm. TSMC was also ahead of Samsung at all subsequent technology nodes. TSMC was behind Intel by less than a year for every new technology nodes. At 20nm, TSMC used CoWoS technology and was lagged behind Intel in 2012 only by a few months. TSMC introduced the first 16nm 3D finFET technology around the third quarter of 2013, while Intel introduced its 14nm technology in early 2014 (CLSA Research, 2012). However, it is important to note that the measurements used to classify “technology generations” are not as clear-cut as before. TSMC’s first 3D finFET technology is viewed as competitive as Intel’s 14nm finFET products (IC Insights, 2014). The 16nm finFET technology can deliver a 25% speed increase with the same standby power consumption as its 20nm planar transistor technology.

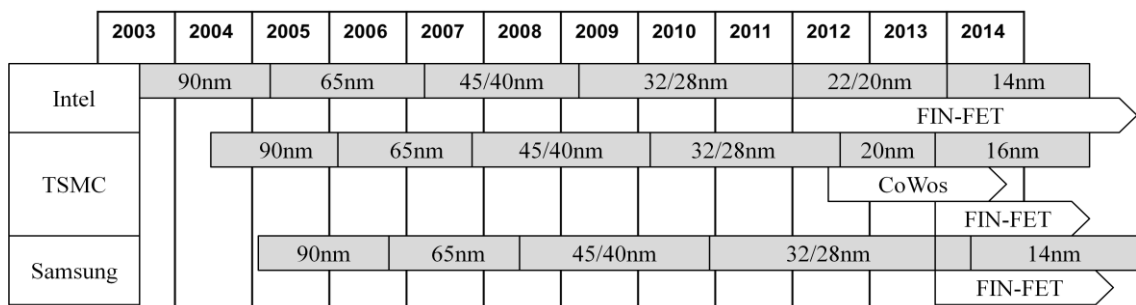
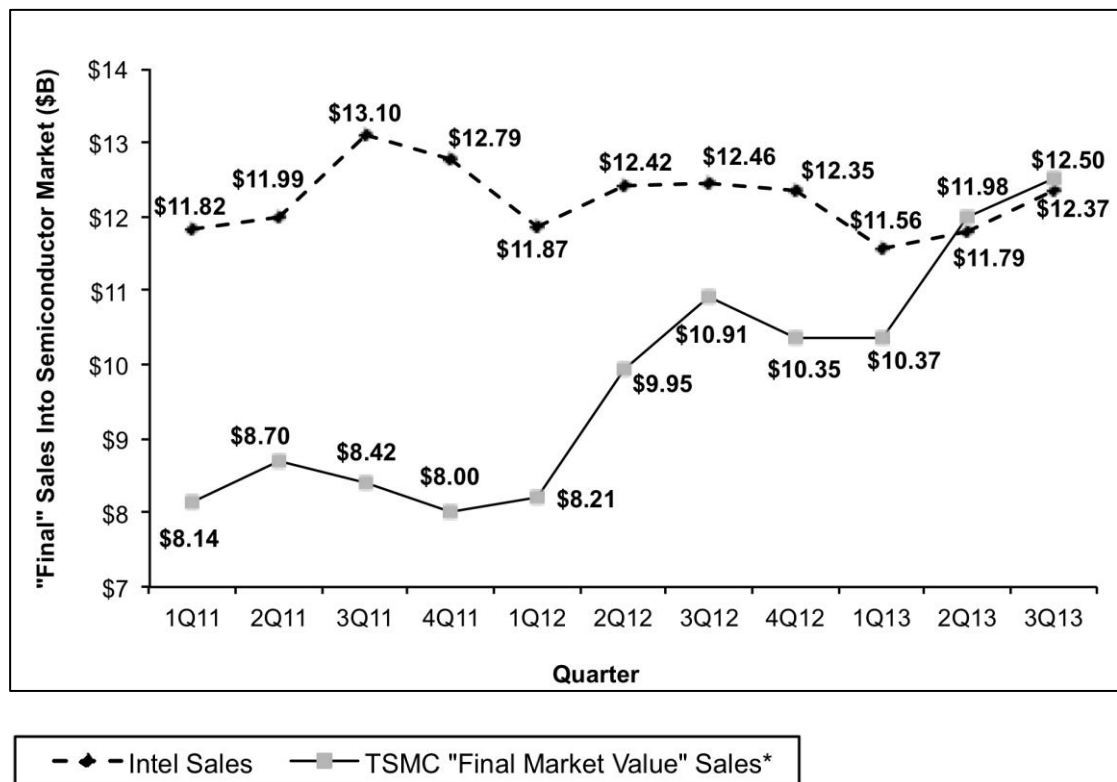


Figure 4.21: Process Technology Development by Leading Foundries
Source: CLSA Research, 2012.

Despite being a contract manufacturer, TSMC has also reduced its gap with frontier IDMs in terms of economic performance. Because TSMC provides services to IDMs and fabless customers, direct comparison between the firm and the branded manufacturing firms is difficult. Industry analysis estimated the increasing role that

foundries gain in the industry by applying a sales multiplier to TSMC's revenue. The formulation of the sales multiplier is as follows. TSMC's sales are significantly weighted toward leading-edge devices (e.g. application processors for Qualcomm) and the average gross margin for its customers is 57% - which equates to a 2.33x sales multiplier (IC Insights, 2014). Figure 4.22 shows that, using that multiplier, TSMC's "final" IC sales came close to the world leading IC firm – Intel as of the end of 2012, with a gap of USD 2 billion. As of 2013, TSMC's "final" IC sales first surpassed Intel's IC sales. This also means that TSMC has a greater influence on the total IC market than any firm in the industry.



Note*“Final” sales assume a 57% gross margin for TSMC's customers.

Figure 4.22: Final Market Value of Semiconductor Sales, TSMC and Intel

Source: IC Insights, 2014.

Table 4.7: Semiconductor Capital Expenditure by Top 25 Firms, 2012-2013.

Firm	2012 (US\$ million)	2013 (US\$ million)	13/12% Change
Samsung	12,225	11,560	-5%
Intel	11,000	10,611	-4%
TSMC*	8,341	9,709	16%
GlobalFoundries*	3,800	4,500	18%
SK Hynix	3,363	3,146	-6%
Micron	2,184	1,935	-11%
Toshiba	1,137	1,630	43%
SanDisk	979	859	-12%
UMC*	1,770	1,098	-38%
SMIC*	499	651	-30%
Infineon	807	490	-39%
ASE**	1,007	668	-34%
ST	476	531	12%
Sony	1,047	574	-45%
TI	494	412	-17%
STATS ChipPAC**	410	508	24%
AMKOR**	533	566	6%
IBM	500	450	-10%
Nanya	141	298	111%
Rohm	535	265	-50%
Hua Hong Grace*	245	300	22%
SPIL*	513	505	-2%
Powertech**	213	236	11%
Avago	254	235	-7%
NXP	251	215	-14%
Top 25 Total	52,724	51,592	-1%
Others	6,316	5,478	-13%
Total Cap Spending	59,040	57,430	-3%

* Foundry

**OSAT firm

Source: Credit Suisse, 2013; IC Insights, 2014.

Moreover, TSMC has also come close to Intel in terms of capital expenditure. As shown in Table 4.7, the firm spent US\$ 9.7 billion on capital expenditure in 2013, as compared to Intel which spent US\$ 10.6 billion (IC Insights, 2014). Nevertheless, it is important to note that Intel gets more leverage from its capital spending, given that the firm earns both a manufacturing and design margin while TSMC only earns from the foundry service. Hence, it appears that Intel has a lower capital expenditure to sales. However,

because TSMC's customers earn the "design margin", by applying 50% gross margin to these customers, TSMC's adjusted capital expenditure to sales ratio is approximately 25%, which is similar to Intel's.

(g) Organizational core competency

The above analysis of TSMC and Intel is not to compare the two firms' technological capabilities and economic performance. Instead, the study seeks to highlight that there is a certain level of "value constellation" practice among leading foundries (such as TSMC) and their customers, in order to ensure that collective end values are created within individual value networks. Moreover, the collective values are competitive as compared to other individual networks. In this case, TSMC has to create values for its fabless or IDM customers by providing frontier process technologies and advanced manufacturing capabilities at competitive costs. In return, its customers also have to provide advanced chip designing technologies that improve the functionalities of chips and provide demand to TSMC. The overall created values allow increasing capital expenditure and technological complexities to be viable options for both the advanced foundries and customers.

On the other side of the coin, around two-thirds of IDMs' final value of ICs derives from the design and less than one-third from manufacturing (CLSA Research, 2012). Hence, IDMs are allocating more towards design R&D instead of wafer fab building and the development of process technologies. Therefore, IDM customers outsource to foundries not only for immediate capacity, but also to gain the support of advanced process technologies.

Although open innovation indicates decreasing prominence of core competency as firms open up themselves for knowledge exchange, the high level of interdependency between upstream and downstream firms in the IC industry means that each participant seeks to

strengthen their specializations. Hence, organizational core competency remains relevant in an environment which firms practice open innovation to form virtual vertical integration.

Despite the fact that Intel, TSMC and Samsung are collaborating with each other in a number of partnerships that involve horizontal scope of technological activities (including participating in ASML's equipment R&D and IMEC's partnership ecosystem), competition exist among these firms such as the race for process miniaturization. Brandenburger and Stuart (1996) refer to this phenomena as "co-opetition" - firms in the industry collaborate but stay competitive with each other.

4.5 Discussion

Because latecomers lack technological capabilities, they are forced to seek external knowledge through various forms of outsourcing at the earlier stage of catch-up. By this means, firms in developing countries can leverage off their temporary low-cost comparative advantage to offer goods and services that are complementary to the incumbents while sourcing knowledge and obsolete technologies of the more advanced firms. Thus, these latecomers are able to capture latecomer effects by overcoming their disadvantages and exploiting their latecomer advantages. This has been the case during the initial stage when third-party outsourcing services (vertical disintegration) became available in the IC industry. Most latecomer cases in this study have pursued this strategy at the beginning of their catch-up. These practices demonstrate the traditional way of value distribution, e.g. the 'industrial view' of value chains as value creation is sequential, unidirectionally transitive and cumulative from one production stage to the other (Ramirez, 1999). However, in time as technology progressed, firms in the industry operated under an environment with increasing open innovation practices that have led to changing industrial structures and value systems.

4.5.1 Business Models and Resource Acquisition Strategies

By providing low-cost manufacturing services, latecomers make use of all the resources they can acquire and leverage from the advanced MNCs during the early stage of their catch-up. For such a trade-off to work, latecomer firms must consciously make strategic choices. By entering into the GVC, some contract manufacturers can develop the potential for upgrading beyond the firm to the national level. It needs to be recognized, however, that not all firms have that organizational capability, and that such opportunities for upgrading may not present themselves. To catch up, latecomers deploy strategies for linking and leveraging more advanced knowledge as posited by Mathew (2002, 2006). However, the findings in this study show that the Taiwanese latecomers did not source for common technologies in Dimension I. The argument as outlined in Mathew's resource acquisition framework (i.e. latecomers to seek least rare, most imitable and most transferable technology) does not hold through different phases due to the changes in industry structure. The Malaysian foundry, although sourced for the most common technology, did not manage to catch up with the world's frontier technology when existing firms in the industry already cumulated the knowledge and capabilities in them.

TSMC created a business model, which enabled the firm to create values for its customers. It was a strategic way to insert itself into the global value chain by reducing the cost burden of its customers. By being the world's first pure-play foundry, it not only created values for its customers, but also created new customers, especially in fabless form. The fabless firms in the US outsourced to the first pure-play foundry (TSMC) not because of lower cost of manufacturing, but because of the ability to avoid manufacturing at all. Such a business model did not exist until the Taiwanese foundry created a path-creating strategy to insert itself into the global value chain.

As informed by earlier literature, innovation has to some extent been open. Using the proposed framework, this study suggests that the practices of open innovation should have at least started to form during Phase I, Dimension III(a) – a period that took place before industry players began to form virtual vertical integration with other actors in their value network. At this point, the concept for value creating system changed. The resource-based view of firms becomes less critical as firms began to form linkages and exchange knowledge with other agents in the value system to achieve collective values. The critical source for organizational competitiveness lies in the ability to integrate internal and external knowledge.

In Phase II, the Taiwanese latecomer firms followed through the practices of open innovation. It is imperative for these latecomer firms to continuously create values for their customers. Latecomer firms can do that in an open innovation environment by pursuing (at least partial) vertical integration. With that, the latecomer firms are able to participate in more production stages and extend their role across the value system. As the latecomer firms build up higher technological capabilities, these firms can offer knowledge in return to the more advanced incumbents, which secure themselves with more linkages to external advanced parties.

4.5.2 Catching Up in Changing Value Systems

The idea of ‘outsourcing’ evolved from the perspective of the incumbents during this period of time. In Phase I, ‘outsourcing’ takes place in two separate forms. On the one hand, the objective of ‘outsourcing’ by incumbents to OSATs in Dimension I is to seek lower cost of production by passing some of the back-end manufacturing to third parties. On the other hand, fabless firms ‘outsourced’ front-end activities to foundries in Dimension I not because it is cheaper than producing on their own, but to have their

production secured since they do not have any fab. The pure-play foundry model exempts the fabless firms from manufacturing.

In the latter part of Phase I as latecomer firms began to move into Dimension III, incumbent IDMs outsource their wafer fabrication activities to pure-play foundries in order to save costs of production as the latecomer foundries have caught up in terms of technological capabilities. As the industry progressed, within the same dimension, more and more incumbent IDMs eventually closed down their fabs to pursue the fab-lite model. As large firms in the industry began to form virtual vertical integration in Dimension III(b), some IDMs have even become fabless. Outsourcing to foundries is no longer an option to save cost, but it has become the principal that underpins the business model of these incumbents.

In time, latecomer firms that look up to virtual vertical integration as a mean to catch up will find themselves a more influential role in their value system in Phase II. In Dimension III(b), TSMC increasingly pursued integration across the vertical chain without compromising the values created for customers. The strategies deployed in Dimension III(b) allow firms to move into Dimension IV(b), of which their technological level becomes at par with their customers. TSMC showcases this phenomenon, of which the introduction of new products of its customers depends on its manufacturing capabilities and process technology development. The relationship between the firm and its customers or suppliers becomes highly interdependent.

In Dimension IV(b), the proposed framework distinguishes the concepts for value constellations. Whereas the previous literature argues that a value constellation is a value creating system in which the coordination of the distribution of values is governed by a 'leader' in that system, the findings in this chapter show that, virtual vertical integration among large firms in the industry leads to high level of interdependency

between partners and so the absence of a dominant leader in that value network. In Phase II, as Taiwanese latecomers gradually formed virtual vertical integration with their networked partners in Dimension III(b), latecomers that arrive even later (in this case, the Malaysian firms) need to break from Dimension III(a) to expand into more production stages so as not to lag further behind.

4.6 Summary

This chapter provided a six-dimensional framework to analyze the dynamic catch-up environment that latecomers faced, as the technology-intensive industry experienced vertical disintegration and virtual vertical integration. Throughout different phases, the firms have to revise and deploy different strategies for resource or knowledge acquisitions. Taiwanese latecomers constantly strategize so that the combination of the external knowledge they acquire and the internal knowledge they build complements each other. Such knowledge integration helped the latecomer firms move up the value chain so as to participate in more production stages and extend their role across the GVC, which in return also attracted various collaborations with external actors. This provided the Taiwanese latecomers with new gateways to more external knowledge.

Latecomer firms shape their business model and resource acquisition strategies in ways that can create values for their upstream customers and downstream suppliers within their value network. However, the concept of value creation also varies as firms travel through different phases and as the industry experiences structural change. The framework and the findings in this chapter suggest that the new phase of value system has allowed latecomers to catch up with frontier technologies, even though they are not OBMs. To make that happen, latecomer firms should at least take into account the different dimensions of resource acquisitions as suggested in this chapter, as well as, the dynamic value systems and industrial structural changes.

CHAPTER 5

ESCAPING FROM ORGANIZATIONAL PATH DEPENDENCE BY ENDOGENOUS COEVOLUTIONARY LOCK-IN WITH INDUSTRY

5.1 Introduction

The chapter analyses the research proposition that if coevolutionary lock-ins enable a firm to control its external environment and to dictate the progress of the industry, whereas ‘vision’ offers the possibilities of path breaking, and a firm’s technological trajectory depends very much on the strategic interpretations of actors and its absorptive capacity; actors thus can lead firms to escape from organizational path dependence through coevolutionary lock ins. What lies at the heart of the generative process has important managerial implications.

5.2 Analytical Framework

Figure 5.1 shows how organizations can skip or break away from the path dependence stage through endogenous coevolutionary lock-in with the external environment, i.e. the industry. This study extends the previous framework beyond the boundary of organizations by linking organizational stages with the evolution of the industry. The proposed framework introduces the element of endogenous forces. Because technological opportunities can be endogenous and is firm-specific (Teece et al., 1997), this study refers to endogenous forces as forces unleashed by an organization into the industry with the objective to generate impact, and to shape and control the technical progress of the industry, often under the top management’s discretion. Endogenous forces can be unleashed at different stages to disturb the status quo so as to engender a coevolutionary reaction between the organization and the industry. Positive feedbacks from the industry act as external forces affecting the organization and result in mutual-

reinforced mechanism (Dobusch & Schüßler, 2012) that leads to inter-path dependence between the organization and the industry over time.

Endogenous forces unleashed with the specific objective of countering organizational lock-in can engender coevolutionary lock-in between the organization and the industry. At that juncture, coevolutionary lock-in works as if the key to unlock organizational path dependence because the coevolutionary lock-in *is* virtually the firm's path-breaking process. If an endogenous force is unleashed *before* the organization progresses into the path dependence stage (i.e. Stage III), it is referred to as the *visionary key* given that vision is constructed based on the beliefs which shape the leaders' views regarding how the firm should compete in the future (Fransman, 1994, 1999). The visionary key can be explained as the moment where preventive actions are taken by the leaders to avoid the potential lock-in. The visionary key can engender coevolutionary lock-in that it allows firms to virtually skip an entire organizational path dependence stage, and hence the organizational path-breaking process so as to forge directly into coevolutionary lock-in (see Figure 5.1).

Because a firm unleashes endogenous forces to generate impact, and to shape and control the progress of the industry; the firm is able to dictate the strategic changes that other agents in the industry – customers, competitors, suppliers, and complementors – must adhere to (Burgelman, 2002, p.350). The industry progresses together with the firm and the coevolutionary lock-in allows the firm to skip to Stage I of its next cycle, where new sets of choices and technological opportunities await.

However, not all firms are able to skip or break away from organizational path dependence through coevolutionary lock-in. First, the organizational leaders need to have the capabilities to envision how the firm should be like in the future by interpreting the external technological opportunities and the firm's existing knowledge base (Cohen

& Levinthal, 1990). The organization then needs to be equipped with the required knowledge base and intensified R&D to pull off the plans. Therefore, endogenous forces are also able to result in higher absorptive capacity of the firm.

The premise is that, organizational path dependence is a fluid process in terms of time. As indicated by Sydow et al. (2009), the duration of each stage does not have to be equal. In addition, there is no clearly demarcated boundary between any two stages and this phenomenon is most apparent when the study incorporates the conditions of the endogenous forces, the visionary key, and the possibility of escaping from path dependence through coevolutionary lock-in with the external environment. This is because: (1) endogenous forces from firms can be engineered any time throughout the stages as they are strategies under managerial discretion at different points in time; (2) the visionary key takes place *before* the path dependence stage (i.e. organizational lock-in); (3) coevolutionary lock-in with the industry is a phenomenon that requires an ongoing interactive process between the organization and the external environment and there is no generalizable point of time in the trajectory that this process *should* or *must* begin.

In addition, this framework incorporates two levels of analysis, i.e. organization and industry. Because these two levels of mechanisms evolve at a different pace and because the system as a whole can never lock into a specific path (Coriat & Dosi, 1998; Bassanini & Dosi, 2001), it is often impossible for the two to be perfectly harmonized at a particular point in time (Garud & Karnøe, 2001). To simplify the study, the analysis is done under the condition that the two are harmonized by incorporating only positive feedbacks from the industry that respond to the firm's specific endogenous forces in an environment with no externalities.

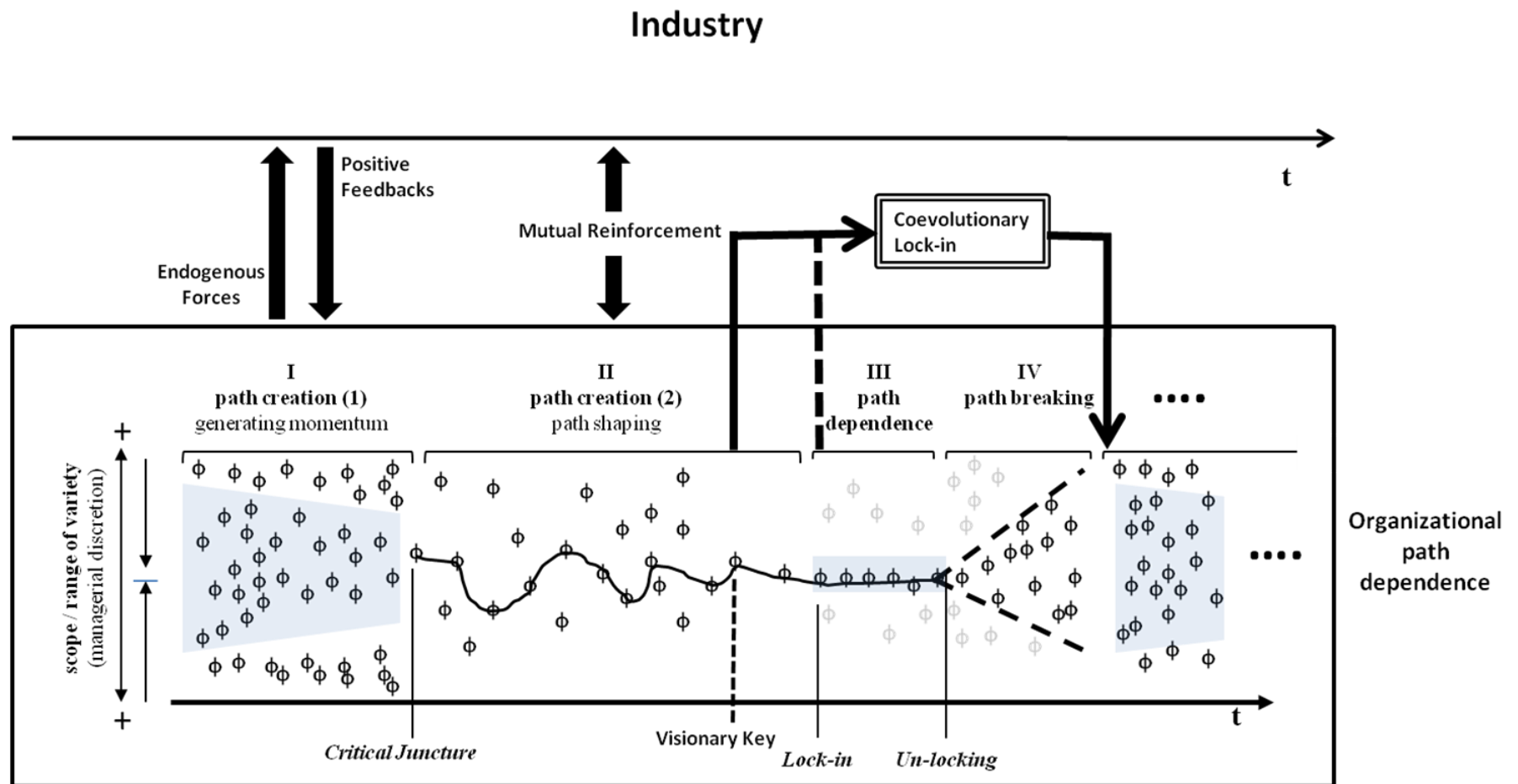


Figure 5.1: Escaping from Organizational Path Dependence through Coevolutionary Lock-In with Industry
 Source: Extended from Sydow et al. (2009).

5.3 Research Method

The study adopts the method of ‘meta-ethnography’ to review and synthesize the existing studies (Noblit & Hare, 1988). The sample used is purposive since the objective is interpretive (Doyle, 2003, p. 326). The resultant synthesis is a reconceptualization across the cases that are related to the research question. This method therefore provides the theoretical and empirical basis for the proposed framework and its propositions.

The chapter examines the propositions through a revelatory case study (Yin, 2014). The case of TSMC has no doubt been studied to unravel the role of Taiwan’s institutions during the nation’s catch-up stage. However, ‘how’ and ‘why’ the firm managed to leapfrog the incumbents and continued to be the industry leader has not been comprehensively unravelled. Non-quantifiable factors like strategic choices and leadership are taken into account.

Specifically, the approach is known as a prototypical case study. A prototypical case is selected because it is expected to become so - its present can be the future of those who read or learn about the case (Rose, 1991, p. 459). Not only the early example allows better understanding of a phenomenon of growing significance, the case can exemplify an archetype of a phenomenon (Rose, 1991) and be particularly useful when there is a ‘proto-theory’ to be tested or refined. A prototypical case study can lead to theory-generating and the case of TSMC is critical for practical lesson-drawing.

Table 5.1: List of Interviews

Organization type	Organization	Position	Key expertise	Main questions
R&D institutes/ Government agencies	1.Bell Laboratories, <i>New Jersey</i>	R&D engineer (1963-1989) ^A	Co-invented the non-volatile semiconductor memory which enabled the development of all modern electronic systems. He was called by the Taiwanese government to return to Taiwan in 1990 to nurture engineering students.	- Key highlights of the IC industry - History of TSMC's establishment - TSMC's success factors
	2.ITRI	Former engineer in ERSO to President of ITRI (1976-2003) ^B	One of the seven engineers who was sent by the Taiwanese government to US in the 1970s to be trained under the RCA technology transfer programme.	- Programs and incentives administered - History of the agencies - Details of technology transfer - History of TSMC's establishment - TSMC's success factors - Key highlights of the IC industry
	3.ERSO	Chief Director (late 1980s) ^C	Led Taiwan's largest and most ambitious National R&D 'Submicron Project'. The project developed Taiwan first 8-inch CMOS submicron manufacturing technology and transformed Taiwanese IC industry to global standard.	- Details of how ERSO developed the CMOS technology - Key highlights of the IC industry
Academia	4.NCTU	National Endowed Chair Professor and UMC Chair Professor ^A	Called by the Taiwanese government to return to Taiwan from Bell Lab in 1990 to nurture engineering students.	- Key highlights of the IC industry - TSMC's success factors
	5.Tsing Hua University	Professor of Technology Management, Morris Chang Chair Professor ^B	Taiwan's leading professor in Technology Management	- Key highlights of the IC industry -TSMC's success factors
IC Firms	6.Macronix	President ^C	Led Macronix to be the world's fourth largest IDM that specialized in non-volatile memory industry.	-How organizational leaders make strategic choices - Key highlights of the IC industry -Firm visions, leadership and strategies

Table 5.1, continued: List of Interviews

Organization type	Organization	Position	Key expertise	Main questions
	7.TSMC	Senior Executive of Integrated Technology	The leader of the Integrated Technology division of TSMC. He has been leading the R&D and technological development of Moore's Law in TSMC for the past 16 years.	- TSMC's visions, leadership and strategies - TSMC's R&D projects, technology development - TSMC's technological capabilities building
	8.Vanguard	Co-founder then President	Vanguard International Semiconductor (VIS) Corporation is a subsidiary of TSMC. It was co-founded by Morris Chang.	- TSMC's visions, leadership and strategies
	9.UMC	Manager of Asia Sales Division and Business Management Two ex-senior engineers	A key leader in UMC's top management. Involved in UMC's R&D projects.	- UMC's strategies - TSMC's technology development - TSMC's competitiveness in the industry - UMC's R&D projects, technology development
	10. ASE	R&D Director	Leads ASE's global R&D projects. Also a researcher in technology management. ASE is the world's largest and most advanced service provider of semiconductor packaging and testing.	- ASE's visions, leadership and strategies - ASE's R&D projects, technology development - TSMC's technology development - TSMC's competitiveness in the industry
Market research firms	11.CLSA Asia-Pacific Markets	Technology consultant and guest author for CLSA semiconductor technology reports (official email communications)	Semiconductor lithography. Besides professing at University of Texas (Austin), his experience ranged from working in established technological organizations including National Security Agency and SEMATECH.	- Technology key performance indicators. - Industry's technology progress and trends - Industry competition - TSMC's competitiveness in the industry - Conditions of TSMC's peers
	12.Macquarie Securities Korea Limited	Managing director – Korea Technology Hardware Research	Technology analysis of semiconductor industry.	

Note: A, B, C = Change of professional roles in the industry.

Source: Interviews, 2012 – 2013.

The prototypical case study is embedded and longitudinal multi-staged. The unit of analysis is TSMC whereas embedded units including top management and R&D engineers are included. The time period of this study is from 1987 to 2013 and it is divided into two epochs. Epoch 1 covers from 1987 to 1999 which is the period when TSMC was catching-up; epoch II covers from 2000 to 2013 which is the period when TSMC began to and continued to lead the industry. Each epoch consists of one cycle of the organizational path as depicted in Figure 5.1. To simplify the analysis, the study includes only external events that act as positive feedbacks from the industry that respond to the firm's specific endogenous forces. Since contextual conditions are important, the study is wary of changes in the industry including market trends and technology demands. Any fact related to the stream of events describing the phenomenon is considered important (Yin, 2014).

One way to examine the propositions is by identifying the 'key informants' to be interviewed (Yin, 2014). The primary data are gained from in-depth interviews and official email exchanges with the key informants. Table 5.1 shows the list of semi-structured interviews undertaken from 2012 – 2013 for the study. These industry experts provide the researcher with perceived causal inferences and help relate the details to the key concepts in the proposed framework. The informants in this study vary in background and represent different R&D institutes, government agencies, academia, IC firms and market research firms. The proposed framework and propositions are also discussed and validated by these key informants. The study complements the above interviews with secondary data obtained from archival records, official documentation and statistical databases.

Firstly, the collected data were organized using the qualitative content analysis method as posited by Gläser and Laudel (2013). This method extracts and processes only the relevant data or information using categories derived ex ante from the prior theoretical

framework. Patterns in the extracted data are identified and integrated (Yin, 2011). To ensure the classifications match both the theory and data, theory was modified in this process if needed.

This study also goes further to produce a stronger test of the first framework. It seeks to treat not just the occurrence of an event, but also how and why an event appeared to have produced a subsequent event (Yin, 2014). To do so, the chapter then examines the ‘transitions’ of the events in the first framework to explain how organizations transit from one particular stage to coevolutionary lock-in, and then to another new cycle of organizational path. The study compares the consistency between the data and the originally stipulated sequence for each event, modifying the latter if needed with additional evidence. In Section 5.4, the organization-level mechanism is explained in Table 5.3 as the study classifies the sequences of events that lead to the generation of endogenous forces. The study also explains industry-level mechanism in Table 5.4 as it classifies the sequences of events that lead to the formation of inter-path dependence and coevolutionary lock-in. Finally, the chapter puts forward a schematic representation of its findings in Figure 5.5, which becomes a new framework for the mechanistic explanation.

5.4 Organizational Path Dependence and Coevolutionary Lock-In

Through the analysis of TSMC’s organizational path, the study shows how TSMC’s endogenous forces interfaced with the industry and resulted in interpath-dependence that caused coevolutionary lock-in with the industry. The latecomer firm encountered different experiences in the two epochs. The study divides the analysis into two epochs. Epoch I is the time period when TSMC was catching up and keeping up with the IC technological development. Epoch II is the time period when TSMC outplayed its competitors and continued to be the leader in logic IC.

5.4.1 TSMC Epoch I: Catch-Up and Keep-Up

5.4.1.1 Stage I: Path Creation (1987-1994)

The founder of TSMC, Morris Chang, received his education in the United States and worked there, rising to the position of Senior Vice President at Texas Instruments. He not only brought with him the tacit knowledge of managing a technology-intensive firm in the same product line but also enjoyed tacit links with the R&D labs, designers, suppliers and buyer firms. While UMC continued to develop the RCA-based (high-voltage) technologies provided by ITRI, Morris Chang envisioned that the RCA-based technologies would not be sustainable in the subsequent years as the process node scales down. Morris Chang therefore led TSMC to form a JV with Philips. His knowledge to envision the limitations of the RCA-based technologies from the beginning is also largely due to his vast experience as the president of ITRI, and since 1980 the President of Hsinchu Science Park.

TSMC began as a latecomer in the IC industry in 1987 but it was determined to be the world's first pure-play foundry. In the 1980s, design-only (fabless) firms outsourced the fabrication of their chips to MNCs that operated as IDMs due to the high cost of production. However, IDMs insisted on the fabless firms transferring the designs via contracts so the IDMs could produce competing chips with their own brand names if a product became successful. Moreover, designs by fabless firms were only fabricated when the IDMs had excess capacity (ITIS, 1999).

Morris Chang, together with other key experts from ITRI who were passionate about developing Taiwan's IC industry at that time, interpreted the technological opportunities and reviewed the knowledge base the new firm could have in Taiwan. It was envisioned that an IC firm could seize the market opportunity given the large number of fabless firms by masterminding a dedicated IC manufacturer to fabricate the designed chips. In

the 1960s, Taiwan had very limited experience in IC design, sales and marketing compared to its experience in process technology at that time. It therefore appeared to Morris Chang and the key experts that Taiwan could develop significant strength in the area of fabrication and a foundry business was built around that strength. The National Endowed Chair Professor stated:

Taiwan is a country with very limited lands, no natural resources and dense population. [...] In the 1960s, Taiwan did not have anything strategic to develop its economy but it had high quality of human capital in the electronics industry and sufficient manufacturing experience in process technologies. This was a critical factor why the second spin-off from ITRI (TSMC) was targeted to be a contract manufacturer for chip fabrication.

It was the first endogenous force unleashed into the IC foundry industry by TSMC. Fabless firms that fully adopted the services of foundries included Nvidia, Adaptec, Altera, Chips and Technologies, Cirrus Logic, and Xilinx. There was an increasingly popular business model and the technological development of the IC industry was quickened, as most fabless firms could by then concentrate their resources on R&D. The former Chief Director of ERSO stated:

TSMC created a path for itself. For the first time, it offered the design firms the support of a dedicated contract manufacturer. Because it was not an IDM, it would not compete with the design firms or prioritize its own manufacturing orders. That created a huge advantage for TSMC because the firm was launching a technological revolution that changed the IC industry's landscape. [...] TSMC's business model allows the 'fabless' firms to focus solely on R&D, to grow without lumpy investments, and to stop sharing their IPs with the IDMs.

5.4.1.2 Stage II: Path Shaping (1995-1998)

The critical juncture of TSMC took place within 1995-1996. Morris Chang led TSMC to gain knowledge via the JV with Philips and to develop an alternative process technology that replaced the mainstream process technology. According to an ex-senior engineer from UMC:

At 0.25um process technology [within 1995 – 1996], the main material [titanium silicide] of the transistor gate was not stable during high-temperature processes in deep-submicron technology. [...] While titanium silicide was the popular process material used by firms including UMC, Morris Chang was able to envision the impending problems and began to develop an alternative process [CoSi₂ gate]. [...] TSMC then smoothly scaled down to 0.18 um and for the first time, it provided the industry a critical next-generation solution.

That event was TSMC's moment of entering into the self-reinforcing process, as it began to lead the foundry industry, both in circuitry resolution and management of manufacturing capabilities. It was that technological initiative by TSMC that began to create a technological gap between the firm and its largest competitor. The ex-engineer added:

UMC, the then world's second largest pure-play foundry which was also TSMC's largest competitor, spent two years catching up with TSMC in yield improvement. 'Two years' is too long in the IC technology competition.

TSMC progressed to be the world's largest pure-play foundry. It was able to price its products at a premium of approximately 10% on a per wafer basis while keeping its customers' costs competitive on a per die basis due to its high die yield and high capacity utilization rates. The firm's average yield rate was above 95%, compared to the industry's average of 80% - 90% (CLSA Emerging Markets, 2005).

TSMC's success and overall high market growth attracted the entry of new foundries. That intensified the industry's competition and eventually caused oversupply and falling prices. IBM's incessant effort in the foundry arena was the biggest threat to TSMC due to IBM's large IP library, resources and knowledge in system-level integration. Meanwhile, choosing the pure-play foundry model causes TSMC to be deprived of IPs in its early stage.

To remain the world's largest pure-play foundry, TSMC strategized an endogenous force that intensified the demand for foundry services. TSMC aggressively expanded its fabrication capacity in 1996 to reach 299,000 wafers per month by 1999, an almost 50% increase from 147,000 wafers per month in 1996. A total of 5 wafer fabs built on 200mm wafer size technology were launched within 1995 – 1998 (Gartner, 2013). Having the highest capacity in the industry, TSMC attracted fabless customers with increasing volume orders and who became more confident with TSMC looking at its rapid expansion. A self-reinforced mechanism developed in TSMC and the scale effect was the most important factor. The Chief Director of ERSO stated:

The promise of high capacity helped TSMC to attract high volume orders, and so realized economies of scale in production to maintain high margins.

TSMC created a significant presence for itself in the industry. However, in this period of time, the wafer shipment (indicator for volume of customer orders) of TSMC was still low. As much as the growth of the fabless firms and their technological innovations were highly dependent on TSMC, the firm needed more manufacturing orders from these firms for its further development. Outsourcing from IDMs was also a new trend which was still not widely accepted. Without more customer orders, TSMC would face difficulties to be the first to develop subsequent technologies, due to its previous choice of becoming a pure-play foundry. There was a potential organizational lock-in.

5.4.1.3 Stage III: Coevolutionary Lock-In (1998-1999)

As a pure-play foundry which has injected much capital and incurred high R&D costs, TSMC had to continue securing itself by keeping up with Moore's Law competition. Because the sources of growth for a pure-play foundry are the fabless firms and the IDMs, TSMC had no choice but to keep growing its customer base by investing intensively although it was already the world's largest foundry. Because the fabless industry was also reliant on TSMC to grow, there was high inter-path dependence between TSMC and the industry.

During Stage III, TSMC had a higher production share from IDMs than in Stage II but it was still low. TSMC could get orders from IDMs only when the IDMs did not have sufficient production capacity or when they decided to cease a particular fabrication technology. The technology consultant at CLSA Research stated:

That was due to longer time to market and transitional inertia as they [IDMs] had to accommodate foundries and standardize processes. [...] IDMs with sufficient volume wanted to avoid foundry price hikes or capacity constraints whereas IP intensive IDMs could better protect their IPs by doing the manufacturing themselves.

In 1998, the industry experienced a cyclical downturn due to the Asian financial crisis. In September 1998, photo-mask manufacturing at TSMC's internal facilities began to decrease. Photo-masking is the earliest sales indicator in the IC production cycle. Being a pure-play foundry, TSMC found obstacles to develop new technologies with decreasing sales. TSMC faced organizational lock-in.

TSMC was challenged by lower utilization rates, but it decided to reduce its production prices for customers who were willing to transfer IP, as part of the firm's strategy to offer SOC solutions. That was another endogenous force unleashed by TSMC from its

top management to increase the organization's absorptive capacity and to build the strongest IP library in the industry.

The senior executive of Integrated Technology division at TSMC opined that such efforts have eventually led to coevolutionary lock-in between TSMC and the industry where new technological opportunities arose for TSMC:

Customers were willing to transfer IPs as they needed the lower prices at the industry's down cycles. Because technologies were crucial for us [TSMC] to grow our customer base, we had to temporarily accept negative margins. [...] We used the transferred IPs to develop a strong design-cell [IP] library to help customers reduce time-to-market and develop SOC designs.

TSMC's strategy of expanding its service portfolio through IP transfers combined with a protracted demand and supply imbalance in the foundry segment further lowered 7% of its own prices (i.e. half of its premium over its competitor UMC) despite the ramp-up of more smaller nodes. The trade-off between lower prices for more sophisticated technology and lower utilization rates again lowered the firm's margins. Moreover, on 29 September 1998, TSMC announced its second JV with Philips which exceeded TSMC's budget plan. TSMC had to continue investing despite the hostile environment.

While its rivals were contemplating on downsizing and cost-minimizing, TSMC incessantly spent on building technological capabilities despite lower margins and lower utilization rates. Those were critical endogenous forces unleashed by TSMC into the industry during the down cycle to ensure that the foundry industry could progress in technology and capacity; hence the advantages of adopting the pure-play model would not be jeopardized. Meanwhile, TSMC gathered critical strengths which opened up itself to more external technological opportunities and very quickly, to a new era of growth. With the strategic discretions of its leaders, the coevolutionary lock-in allowed TSMC to escape from the organizational lock-in.

5.4.2 TSMC Epoch II: Forging Ahead

5.4.2.1 Stage I: Generating Momentum (2000-2005)

TSMC further intensified its R&D and built stronger technological capabilities. Meanwhile, the wafer-bumping process became more important in the industry as it is a key manufacturing process for the flip-chip market which was expanding.⁹ TSMC gained high market shares in advanced nodes but packaging and testing firms like ASE, did not expand wafer-bumping capacity enough to meet TSMC's customers' requirements. According to the senior executive of Integrated Technology division, TSMC integrated wafer fabrication with wafer-bumping process in 2000:

The purpose of developing the wafer-bumping in our [TSMC's] fab was to internalize the relevant knowledge into the organization while quickening technical progress in the wafer bumping sector so that it was in sync with the speed of the firm's node miniaturization.

Since bumping is a wafer-based process, knowledge- and technology-intensive foundries have an advantage over packaging and testing firms as technology barriers increase. Wafer-bumping also has a similar equipment and cost structure with wafer fabrication. Morris Chang was aware of the potential obstacles facing technology migration into smaller nodes; and he too was aware of the organization's existing knowledge base and financial structure which could afford the additional venture. TSMC's integration of advanced bumping was another endogenous force unleashed upon the industry. The firm turned a constraint into an opportunity. It built its own wafer-bumping capacity, especially at technology-intensive nodes to solve production bottlenecks that it would otherwise face and overall to avoid any deceleration of the industry's technology migration.

⁹ Bumping is a process immediately after fabrication, which takes place before packaging and testing (CLSA Research, 2012). After fabrication, wafers are sent to packaging and testing firms for subsequent processes.

TSMC's miniaturization technology caught up with the world's frontier in 1998. Since then TSMC has led the industry's process roadmap, overtaking the MNC incumbents. Leading fabless firms were increasingly seeking foundries to prototype their advanced circuit designs. The senior executive of TSMC's Integrated Technology division added:

Foundries have diverse customer bases. This means we [TSMC] can learn the full range of IPs and manufacturing processes better than the IDMs. [...] The technological gap between foundries and IDMs began narrowing quickly so much so that the process technology of advanced foundries, especially us [TSMC], had caught up with that of the top-tier IDMs.

TSMC's progressive technology was an endogenous force that has hastened the speed of node miniaturization, resulting in higher market needs for smaller nodes. This is an example of industry's feedback as an external force to TSMC. TSMC continued to push the frontier of node miniaturization. Such mutually-reinforced mechanisms resulted in the need for IDMs to outsource to foundries due to the escalating costs of setting up fabs catering to the production of smaller nodes as the industry progressed (see Figure 5.2). Endogenous forces unleashed by TSMC resulted in inter-path dependence between TSMC and the industry.

TSMC's knowledge in node miniaturization led the firm to easily build the most extensive process technology portfolios and service offerings. It became a one-stop total solutions provider. For instance, 90% of TSMC's customers utilized the foundry's photo-masking services and these customers were highly dependent on TSMC since photo-masks are generally non-portable (CLSA Research, 2012).

The senior executive of TSMC's Integrated Technology division added:

Our progressive R&D in node miniaturization led us to easily extend the R&D scope to add features and services to each existing node. We are leading both in Moore's Law and More than Moore's Law. [...] This is crucial to avoid excess capacity that lowers our production scale effect. [...] We now have the most extensive process technology portfolios and service offerings as a one-stop solution provider.

IDMs encountered stiff competitions from fabless firms as the fabless model does not require high fixed costs and they had better production yields and pricing by outsourcing to foundries. Fabless firms were also more competitive with more cost effective designs. A number of IDMs became relying on TSMC for advanced nodes, larger wafers, and strong integration capabilities.

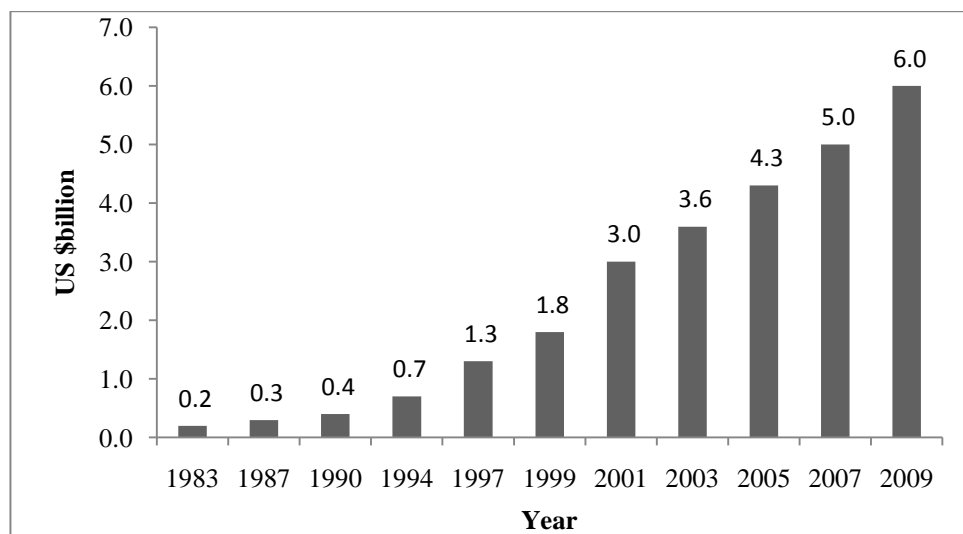


Figure 5.2: Cost of Setting Up a Wafer Fabrication Plant, 1983-2009
Source: CLSA Research (2012).

5.4.2.2 Stage II: Path Shaping (2006-2010)

Since TSMC began to lead the technologies in the logic IC industry, it had to risk the high costs involved to develop new processes including the initial phase of equipment inefficiency. However, driven by Morris Chang's visions, TSMC continued to lead node miniaturization. TSMC was challenged with yield instability in the development

phase of increasingly smaller nodes. The firm's profitability was hampered and its cost savings was jeopardized. Meanwhile, many IDMs began to cease their wafer fabrication due to less economy of scale compared to TSMC. These firms could not achieve optimal production scale as they did not open up their fabs to offer foundry services.

According to the Morris Chang Chair Professor:

IDMs only produce their own branded chips. Those [IDMs] with smaller scale face higher cost per unit as pure-play foundries like TSMC produce large volumes. A large foundry arm of an IDM could have similar strength; but IDMs still had to choose spending on R&D and designing over production. Many IDMs eventually moved towards a fab-lite or a fabless model.

As IDMs stopped building their own fabs and gradually adopted the fab-lite model, they increasingly outsourced to foundries. When TSMC arrived at 28nm, only five IDMs worldwide were able to survive, as compared to 10 IDMs at 45nm and 16 IDMs at 90nm node (CLSA Research, 2012).

TSMC was the first to launch 65nm node and that was the critical juncture for TSMC as it led to self-reinforced effects in subsequent periods. The pricing of each node is the highest at the first quarter of every introduction and fell dramatically through the subsequent quarters. Latecomers of technology nodes are constrained by lower prices and discount offers, thus having less ability to recoup their investments. The President of Macronix commented:

The premiums earned for being the first-mover of a new technology node also assisted TSMC to have sufficient resources to invest in the subsequent smaller nodes, related R&D and production capacity.

This cumulative, self-reinforced mechanism has enabled TSMC to be the R&D frontrunner in logic IC (see Figure 5.3); all of which allowed TSMC to unleash more endogenous forces to push the technological frontier of the industry. TSMC was also

the first to sell at 45nm and 28nm.¹⁰ It is almost unviable for UMC to further venture into 22nm as the firm's average return on gross equity for that node is merely 2% versus 9% for TSMC (CLSA Research, 2012). The manager of Asia Sales Division at UMC noted:

TSMC raised the bar of R&D expenditure among industry players and was the first to build massive capacity. [...] TSMC keeps widening its technological and time gap with its peers. We [UMC] cannot keep up with the race but we still have to follow TSMC's technology.

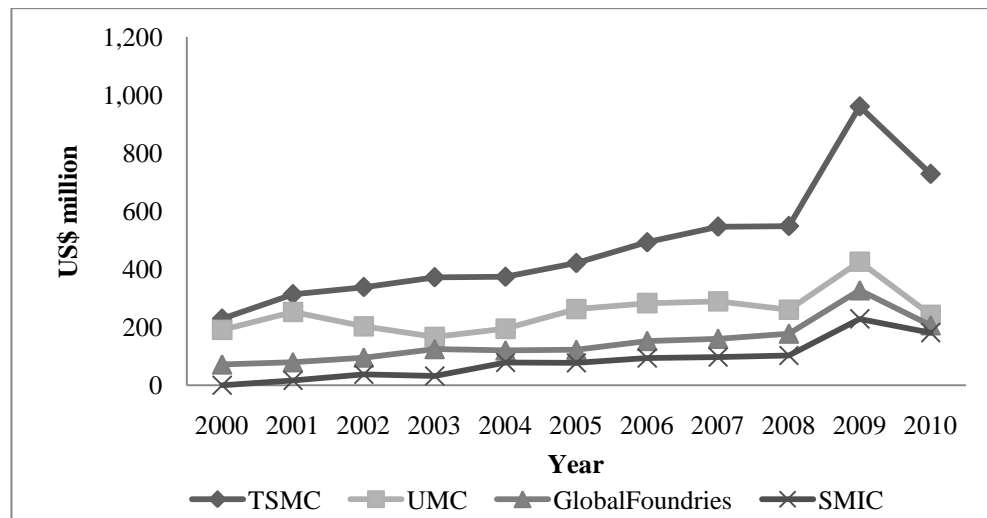


Figure 5.3: R&D Expenditure of the Largest Pure-Play Foundries, 2000-2010
Source: CLSA Research, 2012.

While other foundries were trying to expand the lifetime of their existing fabs to avoid capital spending, TSMC disrupted the industry's status quo by continuously building more fabs. By 2012, TSMC owned a total of 19 operating wafer fabs. 10 of the wafer fabs began production in 2004 and after, which was when the building costs were skyrocketing (CLSA Research, 2012). Figure 5.4 shows TSMC's capital spending compared to its competitors.

¹⁰ Miniaturization of memory chips is faster and costs much less than logic chips as its fabrication involves building transistors in repetitive structures in contrast to complex built-up of individually-located transistors in logic chips (CLSA Research, 2012).

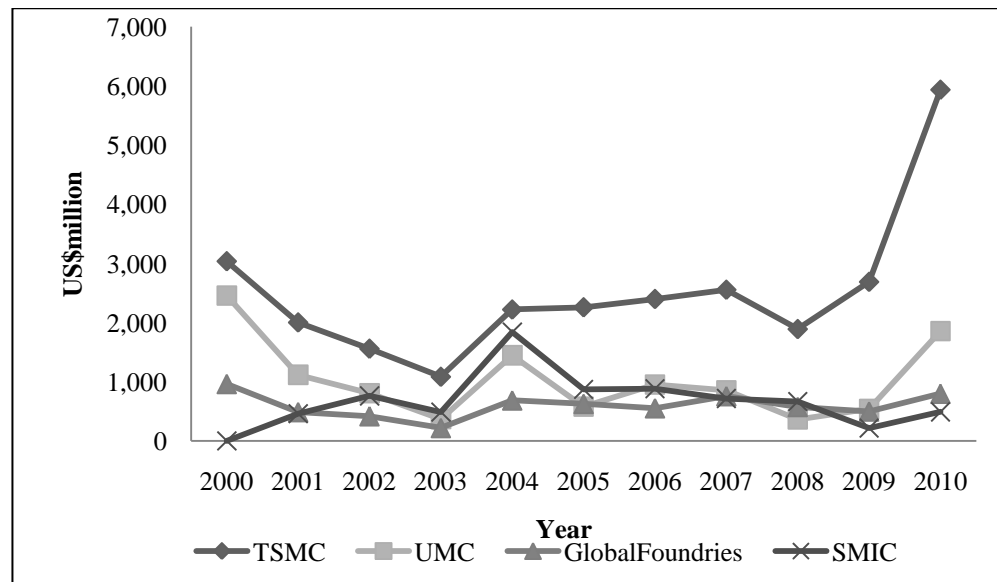


Figure 5.4 Capital Expenditure by the Largest Pure-Play Foundries, 2000 – 2010
Source: CLSA Research (2012).

5.4.2.3 Stage III: Coevolutionary Lock-In (2011 – mid 2013)

Morris Chang envisioned in 2007 that the industry would face major structural change as Moore's Law will be obstructed by unsolvable technical challenges in the following six to eight years. Such bottlenecks would cause TSMC to lose all its self-reinforced benefits accumulated from its technological leadership. Morris Chang and the top managers strategized to interfere with the industry's status quo to prevent negative impacts likely to hit the firm. He envisioned that it was crucial for TSMC to vertically integrate its technological activities to counter Moore's Law bottlenecks.¹¹ In fact, this was the period of time when TSMC began to pursue virtual vertical integration, as discussed in earlier chapters.

Morris Chang revised the firm's business model and interpreted that, TSMC has wafer-level knowledge to integrate into advanced wafer-level packaging such as 3D packaging and CoWoS. Morris Chang then announced in a number of press conferences in 2007

¹¹ Although the event of visionary key took place in 2007, the topic is discussed together with Stage III in order to explain how the visionary key helps the firm mitigate the technology bottlenecks caused by the challenges to Moore's Law.

that TSMC would vertically integrate its scope of technologies (Chang, 2007; CLSA Research, 2012). The President of Macronix commented that:

It was important for TSMC to secure its leading position because of all the cumulative advantages. Moore's Law bottlenecks are 'red lights' to TSMC. [...] The firm definitely has the relevant knowledge and skills to integrate into advanced 3D packaging.

The senior executive of Integrated Technology division noted how the CoWoS technology created new opportunities for TSMC:

We [TSMC] integrated wafer manufacturing with 3D packaging of finished products to deliver successful customers' product development and to achieve faster time-to-market with improved system performance.

The Morris Chang Chair Professor noted:

With 3D packaging capabilities, TSMC is creating new values across the value chain and these values belong to TSMC.

The R&D director of ASE added:

We cannot keep up with TSMC's CoWoS development but we are definitely following this [CoWoS]. We have started the internal R&D.

Being the leader in Moore's Law competition, CoWoS was introduced to escape from a potential organizational lock-in. Such endogenous force is reckoned as the visionary key of TSMC. By 2012, TSMC was the first and only foundry to officially initiate production for CoWoS. In that year, almost 50% of chips larger than 120mm were transforming to adopt CoWoS (CLSA Research, 2012). This endogenous force by TSMC is capable of changing the industry landscape and allowing TSMC to be in

further control of the industry. TSMC skipped the internal lock-in caused by deceleration of Moore's Law via the coevolutionary lock-in.

In 2012, Intel began shipments of its 22nm chips which were produced with the FinFET process.¹² Under Morris Chang's leadership, TSMC had the knowledge base and existing capacity to conduct FinFET R&D. In April 2013, TSMC announced the first tape-out of a processor co-developed with ARM using TSMC's 16nm FinFET technology. However, fabless firms in the industry faced difficulties to design circuits with FinFET as the EDA vendors who supplied chip design tools were not ready to cope with the 3D transistor structure. TSMC again interfered with the industry's progress by facilitating the industry's adoption of the new technology. The senior executive of TSMC noted:

We [TSMC] certified the list of custom and digital design tools from Synopsys for 16nm FinFET Design Rule Manual [...] The certification provides the early adopters access to our [TSMC's] advanced process and to facilitate the industry's deployment of FinFET.

Such endogenous force contributed to TSMC's coevolutionary lock-in with the industry. As much as TSMC had to commercialize FinFET in the IC industry to avoid internal production bottlenecks, the industry needs FinFET to continue to progress as Moore's Law slows down. The findings are summarized in Table 5.2.

¹² FinFET is a multigate transistor architecture developed to solve scalability bottlenecks when the IC industry migrates beyond 20nm (CLSA Research, 2012).

Table 5.2: TSMC's Organizational Path, Inter-Path Dependence and Coevolutionary Lock-In with the Industry

<i>Epoch</i>	Epoch I (1987 - 1999)			Epoch II (2000 - 2013)		
<i>TSMC</i>	Path creation (1987 - 1994)	Path shaping (1995 - 1998)	Coevolutionary lock-in (1998 - 1999)	Generating momentum (2000 - 2005)	Path shaping (2006 - 2010)	Coevolutionary lock-in (2011 - 2013)
<i>TSMC's endogenous forces</i>	Became the first pure-play foundry.	Developed the alternative process to solve thermal issue and for the first time provided the critical next-generation solution (critical juncture). Expanded production capacity.	Began building the strongest IP library by reducing prices to customer willing to transfer IPs; invested in technologies and manufacturing capacity despite industry downturn.	Intensified its R&D and integrated into wafer bumping; built the most extensive process technology portfolios and service offerings.	Pushed the frontier of node miniaturization, wafer size, and production yield. Envisioned to vertically integrate the firm's technology offerings (the visionary key) and began to pursue virtual vertical integration in 2007.	Integrated into advanced packaging (CoWoS); certified EDA design tools to facilitate industry-wide adoption of FinFET technologies to counter Moore's Law bottlenecks.
<i>TSMC and Industry</i>	Inter-path dependence		Coevolutionary lock-in	Inter-path dependence		Coevolutionary lock-in
<i>Industry's positive feedbacks</i>	Fabless firms began to outsource to foundries.	Fabless firms relied on TSMC's large capacity to produce at larger volumes.	Lower demand at industry downturn; customers had to transfer IPs to TSMC to get lower prices.	Firms' miniaturization relied on TSMC's production capabilities. More IDMs outsourced to foundries due to high fab costs and stiff competition from fabless firms as they have better yields.	A large number of fabless and IDMs relied on TSMC for success; as more IDMs went fab-lite or fabless.	Advanced fabless firms and IDMs adopted CoWoS and FinFET technologies to mitigate production bottlenecks.

Source: Interviews, 2012-2013.

5.5 Discussion

The IC industry is a technologically complex industry. Hence, it will be too ambitious to incorporate all technological aspects of the industry into this chapter. However, the technological events selected for this study are the fundamental pillars of the IC industry and are critical features that contribute to the development of the industry.

The Epoch I of TSMC case is an example of how a leading firm escaped from organizational lock-in in a short period of time by unleashing endogenous forces into the industry, which eventually led to a coevolutionary lock-in. The Epoch II of the firm is an example of how a leading firm unleashes endogenous forces targeted at countering a specific impending organizational lock-in during the path shaping process (Phase II). Table 5.3 presents the findings on TSMC's firm-level generative process of endogenous forces whereas Table 5.4 presents the formation process of TSMC's inter-path dependence and coevolutionary lock-in with the industry. The new framework that shows the process of engendering endogenous forces and coevolutionary lock-in is presented in Figure 5.5.

If the industry's feedback on the organization's endogenous forces is positive, the mutually reinforced mechanisms can disturb the status quo and lead to inter-path dependence between the organization and the industry. Some inter-path dependence may eventually progress into coevolutionary lock-in of the organization and the industry while some may not. Nonetheless, inter-path dependence opens up new technological opportunities for the organization. Endogenous forces unleashed during the phase of organizational lock-in that leads to coevolutionary lock-in help the firm break away quickly from internal path dependence. At this juncture, the coevolutionary lock-in works as the un-locking key.

When endogenous forces are unleashed before the internal lock-in, they are referred to as the visionary key. Instead of going through organizational path dependence, visionary key allows industry leaders to virtually skip the entire organizational lock-in phase and progress directly into coevolutionary lock-in with the industry. Because endogenous forces unleashed by the firms are able to generate impact, and to shape and control the technical progress of the industry, these firms are also able to skip the organizational path-breaking process as the industry progresses concurrently with the steps of the leading firms.

Path dependence emphasizes how history carries through time in the genesis of novelty but not so much the role of actors in the process of that genesis, which is also important for the understanding of sources that shape history, path breaking and path creation (Garud & Karnøe, 2001). The study's approach sheds light on the leader's role by conceptualizing the generative process of organizational path breaking and path creation. The key factors that contribute to successful endogenous forces include vision constructions of the firm leaders and the firm's absorptive capacity. Successful endogenous forces are well-planned strategies appropriated by firm leaders based on their ability to envision how the firm should be in the future by interpreting the external technological opportunities, the firm's existing knowledge base, and how the two can be synergized. The organization needs to have the requisite knowledge base to set in motion the well-planned endogenous forces. However, vision reconstruction is also needed if an endogenous force does not yield positive feedbacks from the industry that can progress into productive outcomes.

Table 5.3: TSMC's Generative Process of Endogenous Forces

[Potential] organizational lock-in ➡	Interpreting external environment ➡	Interpreting existing knowledge base ➡	Vision construction ➡	Endogenous forces ➡	R&D intensity
N/A	Fabless firms faced constraints by subcontracting to IDMs	Taiwan had process manufacturing capabilities	A pure-play foundry can tap the fabless market	The world's first pure-play foundry	+
The use of titanium silicide would not be sustainable	It was the mainstream material	TSMC could learn from Philips through the JV	To be the first to give solution to the industry	Developed the critical alternative	+
IBM foundry as a threat due to system-level IPs, resources and knowledge	The demand for TSMC's service could increase if it had higher capacity	Could handle higher production due to strong human resource	To be the foundry with highest production capacity	Aggressively expanded production capacity	Not applicable
TSMC's growth was jeopardized without enough orders at downturn	Industry downturn and customers needed lower prices	Experience with customers allowed TSMC to assimilate the transferred IPs	To build the strongest design cell libraries in the foundry industry	Transferred IPs from customers and built the strongest IP library	+
Technology deceleration as packaging firms could not keep up with TSMC's speed of miniaturization	No foundry house was operating wafer-bumping	TSMC has high level of skills in wafer-level technologies	To provide wafer-bumping in-house to avoid technology deceleration	Developed in-house wafer bumping activities and pushed the technical frontier	+
The need to turn IDMs into TSMC's customers	Fabless were less competitive compared to IDMs	TSMC gained strong knowledge base in previous nodes	To become a one-stop solutions provider by adding features at nodes	Built the most extensive technology portfolio and services	+
TSMC could not afford to lose its pricing advantages	Competitors could not keep up in node miniaturization	TSMC has been leading in node miniaturization	To continue lead Moore's Law to win pricing advantages	Pushed the miniaturization race to create a huge gap with rivals	+
Could lose self-reinforced benefits due to Moore's Law bottlenecks	An increasing technology gap between TSMC and the rest	Most technologies are internalized in TSMC	To counter Moore's Law bottlenecks	Vertically integrated technology offerings (visionary key)	+
Moore's Law bottlenecks	Industry needed alternative ways	TSMC's strength is wafer-level technology	3D packaging as a technology alternative	Introduced CoWoS technology	+
Moore's Law bottlenecks	Customers (fabless) could not transit to FinFET smoothly	Easy to transit to 16nm FinFET due to similar technologies at 20nm	Able to tap and be ahead of other foundries if facilitate EDA tools	Certified EDA design tools from Synopsis	+

Source: Interviews, 2012-2013.

Table 5.4: The Formation Process of TSMC's Inter-Path Dependence and Coevolutionary Lock-In with the Industry

Endogenous forces	➡ Positive feedbacks from industry	➡ Mutual-reinforcement, Status quo disturbed	➡ Inter-path dependence/ Lock-in	[Inter-path dependence/ Lock-in]	➡ Accumulation of absorptive capacity
Became the world's first pure-play foundry	Fabless firms relied on TSMC to grow	+	TSMC and the fabless needed each other to grow	Inter-path dependence	Not applicable
Developed an alternative for titanium silicide	The industry migrated from the mainstream material	+	Lead the industry in circuitry resolution and manufacturing management	Inter-path dependence	New technological path
Aggressively expanded capacity	Fabless became more confident with TSMC and outsourced more to TSMC	+	TSMC achieved production scale as fabless grew larger by producing at higher volumes	Inter-path dependence	Path-dependent
Built the strongest IP library in the foundry industry	Industry experienced downturn and customers needed lower prices	+	Customers transferred more IPs and TSMC continued to lower prices	Coevolutionary lock-in	Deepening
Developed in-house wafer-bumping	TSMC provided rooms for customers to continue miniaturize	+	More firms relied on TSMC as it grew larger	Inter-path dependence	Deepening, integration
Built the most extensive technology portfolio and services	Customers became sticky, fabless became more competitive, IDMs began to rely on TSMC	+	TSMC strengthened sales and capabilities while industry's progress was accelerated	Inter-path dependence	Deepening, widening and integration
Pushed the node miniaturization frontier to create a huge gap with rivals	Increased numbers of IDMs went fab-lite due to cost disadvantages	+	IDMs relied on foundries and first-mover benefits continued to push TSMC to miniaturize	Inter-path dependence	Path-dependent, deepening
Vertically integrated technology offerings (visionary key)	Large fabless prefer foundries that provide integrated services	+	TSMC had to stay as the largest foundry and customers needed an integrated foundry as the industry was concentrated	Coevolutionary lock-in	Deepening, integration
Introduced the CoWoS technology	The industry needed 3D packaging to mitigate Moore's Law difficulties	+	Both industry and TSMC had to continue solving Moore's Law bottlenecks	Coevolutionary lock-in	New technological path, integration
Certified EDA design tools from Synopsis	The industry needed FinFET technology to mitigate Moore's Law difficulties	+	Both industry and TSMC had to continue solving Moore's Law bottlenecks	Coevolutionary lock-in	Deepening, path-dependent, integration

Source: Interviews, 2012-2013.

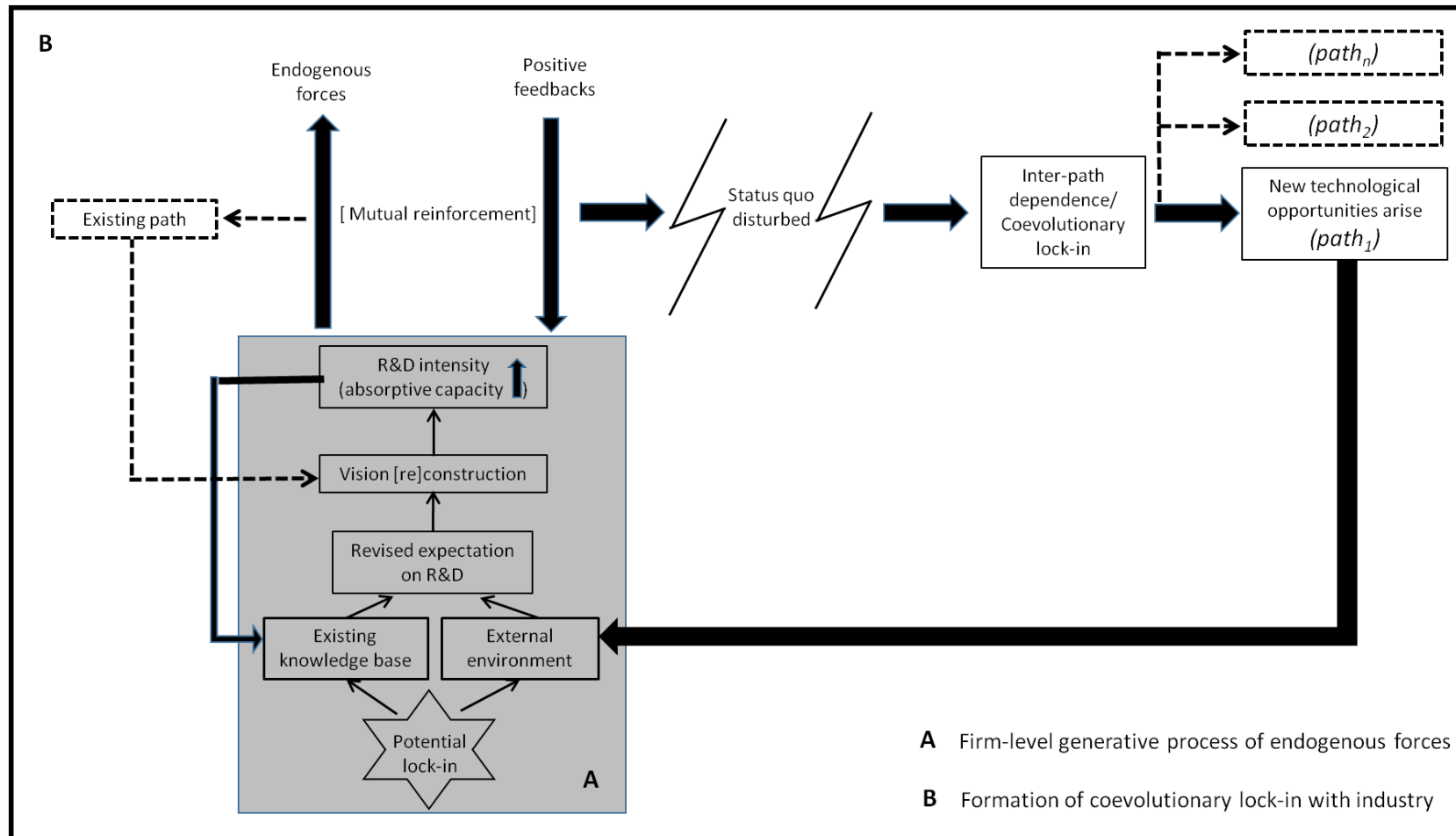


Figure 5.5: Firm-level Generative Process of Endogenous Forces and the Formation of Coevolutionary Lock-In with Industry
Source: Authors.

Through higher R&D intensity, endogenous forces should also increase the firm's absorptive capacity that, because it is cumulative, will be carried through to subsequent phases. During Epoch I, TSMC focused on its specialization and intensely built its capabilities for process technologies of logic ICs. Therefore, the knowledge and skills accumulated were path-dependent, bringing a deepening effect to TSMC's technological capabilities in Epoch I. Since the middle of Epoch II, TSMC began to pursue virtual vertical integration. Such efforts helped TSMC to vertically integrate the scope of technological activities while further deepening its core competency.

5.6 Summary

This chapter extended the perspective of organizational path dependence to stretch beyond the boundary of organizations by integrating firm- and industry-level analysis. Rather than concentrating on the theorizing of the organizational path-dependence process, the study focused on how organizations can escape from internal lock-in to explain why TSMC, although beginning life as a latecomer, has leapfrogged the incumbents and has continued to be the world's leader in the logic IC industry. TSMC was able to take industry leadership by unleashing endogenous forces that interfered with the industry's progress. Positive feedbacks from the industry caused a mutually reinforcing set of mechanisms between the firm and the industry that eventually disturbed the status quo. Such inter-path dependence resulted in coevolutionary lock-in of the firm and the industry.

The visionary key allows industry leaders to virtually skip the entire organizational lock-in phase, including the path-breaking phase in the Sydow et al. (2009) framework. Because the firm is able to generate impact, to shape and dictate the technical progress of the industry, the resulting coevolutionary lock-in opens up new technological

opportunities for the firm. New technological opportunities thus become endogenous to the firm. Through higher intensity of R&D, endogenous forces from firms can also increase their absorptive capacity, which will facilitate better interpretation of external opportunities. These effects are cumulative and carried through to subsequent phases.

Industry leaders, such as TSMC, have appropriated the advantages of endogenous forces and coevolutionary lock-in to escape from potential inefficiencies caused by internal path dependence. Evidence shows that TSMC has focused on this strategy to maintain its leading position in the logic IC industry. Firms not able to unleash endogenous forces that lead to coevolutionary lock-in are trapped within their internal path dependence for a longer time, carrying cumulative inefficiencies into their future. The industry followers, such as UMC, Globalfoundries and SMIC, have been following the footsteps dictated by TSMC without unleashing significant endogenous forces into the industry. The extended Sydow et al. (2009) framework and the new framework introduced in this chapter can be helpful to understand organizational theories and industrial dynamics, especially on firm-level endogenous forces and coevolutionary lock-in. The new framework also helps shed light on the generative process of path breaking and path creation.

CHAPTER 6

CONCLUSIONS AND IMPLICATIONS

6.1 Introduction

Previous research on latecomer catch-up has informed us regarding the critical role of institutions and organizational capability building. However, understanding latecomer catch-up in a technology-intensive industry also requires a deeper scrutiny of how the technological regime works and how the industry structure evolves. This study begins with an analysis at the technology-level, with the objective to examine the mechanisms of the changing technological regimes of the IC industry. Subsequently, the thesis seeks to examine the latecomer resource acquisition strategies to catch up in an industry with evolving structures and value systems. The thesis then conducts a case study on the world's first pure-play foundry to understand how the firm strategized to build its technological capabilities so as to lead the industry through different phases. The findings of this research provide important implications for theory, firm management and policies, which will be described in the latter part of this section.

6.2 Synthesis of Research

Driven by the identified research questions, this research developed three different frameworks to examine the mechanisms of technological transitions, latecomer resource acquisitions in changing industrial structure and value systems, as well as how firms build technological capabilities through coevolutionary lock-in. The following recapitulates the objectives and main findings of this study.

6.2.1 Technological Transitions

The first analytical framework examines the mechanisms behind the changing technological regimes and how industry's innovation patterns are affected. It shows how technological regimes lead to changing industry driving forces, organizational vertical boundaries and network boundaries which together produce a feedback loop in the system. Functional roles are assigned across fabless and foundries in the IC industry, firms adopt modular or networked modular organization systems according to the degree of the industry driving forces.

The concept of technological regime is useful to understand the mechanisms behind industrial progress in the IC foundry industry. The framework first identified the most relevant dimensions important in capturing the forces that shape the technological regime of the IC industry. Technological interrelatedness, cumulativeness, economies of scale, technological opportunities, and technological appropriability are important dimensions in the IC industry.

Empirical analysis shows that higher economies of scale can widen the gap of manufacturing capabilities among fab owners. Meanwhile, lower technological opportunities among smaller firms but higher technological appropriability among larger firms widen the gap of technological capabilities among these firms, which happened during Phase II of the IC industry. The factors have resulted in the large foundries integrating vertically, though not fully, whereas smaller firms remain as specialized but fragmented firms. Overall, these have resulted in an industry characterized by high stability of innovators, lower entries but higher exits thus highly concentrated innovations.

The findings in this chapter have important technological learning implications. It examines the transition process of an industry shifting its characteristics between Schumpeter Mark I and Schumpeter Mark II. In doing so, the study first found that the formation of industry's technological regime is endogenous as firms make choices to their organizational boundaries that create feedback loops to the technological regime. In Phase II, large firms react to such conditions by strengthening their external linkages in order to secure their leading positions in the market. Such strategies enable firms to gain more technological capabilities and synergies among firms, which allow rooms for lower R&D cost, higher economies of scale etc.

Second, examining the transition process allows us to identify specific dimensions of technological regime that are appropriate for latecomer firms to strategize for catch-up in a Schumpeter Mark I environment. Meanwhile, under a Schumpeter Mark II environment, higher degree of economies of scale, lower technological opportunities and higher technological appropriability provide promising conditions for latecomers – which have successfully caught up - to strategize to leapfrog the large incumbents in order to become industry leaders.

6.2.2 Latecomer Resource Acquisitions

The second analytical framework in the study examined the latecomer resource acquisition strategies to catch up in a technology-intensive industry that faced changing industrial structures and value creating systems. Latecomers are faced with increasing complexities to catch up in a high-tech industry, especially when it comes to acquiring external knowledge as large firms in the industry determine the changes of value systems. The proposed framework takes into consideration the changing industrial

structures and value systems to suggest an alternative view of catch-up strategies in a dynamic environment like the IC industry.

To understand how latecomer firms shape their business models to create values for their customers and to extend their role in the GVC across different phases, the analysis of the framework incorporates the resource acquisition strategies identified in previous research (i.e. linkage, leverage, learning and technological rareness, imitability and transferability) (Mathews, 2002, 2006). Using the proposed dimensions in the framework, the study is able to craft the catch-up paths taken by the latecomers via changing value systems.

The findings in the study show that, latecomer firms like TSMC and ASE have adopted path-creation strategy and acquired the least common technologies during the initial stage of their catch-up. Meanwhile, UMC has been a fast-follower. These Taiwanese latecomer firms have effectively moved from Dimension I to Dimension III while TSMC has arrived at Dimension IV. The fabless firms in the US went to the first pure-play foundry (TSMC) not because of lower cost of manufacturing, but because they did not have to build any expensive wafer fab. It was a path creating strategy to insert into the GVC. However, the findings also show that latecomer firms from Malaysia have not been able to catch up effectively by being a slow path-follower, despite mimicking the Taiwanese strategies. The changing industrial structures and the value systems require firms to deploy different strategies to acquire external knowledge at different phases.

Nevertheless, it should be noted that, different forms of production specialization and different points in time of catch-up lead to different learning processes due to different technological regimes faced by the firms. For instance, as compared to the packaging and test firms in this study, the foundries faced a technological regime with higher

cumulativeness and higher economies of scale. These two dimensions caused the foundry industry face very stiff price competition all the time. Such dimensions have also led to the fact that, the packaging and test firms are still able to perform financially well although they have not achieved significant vertical upgrading.

6.2.3 Organizational Capability Building

The third analytical chapter extends the perspective of organizational path dependence by integrating firm- and industry-level analysis. Instead of focusing on the theorizing of organizational path dependence process, the study focuses on the process of how organizations can break away from internal lock-in to explain firm differences. The study explains why TSMC, although began as a latecomer, has leapfrogged the incumbents and has continued to be the world's leader in the logic IC industry. The Epoch I of the TSMC case is an example of how a leading firm escaped from organizational lock-in in a short period of time by unleashing endogenous forces into the industry, which eventually led to a coevolutionary lock-in. The Epoch II of the firm is an example of how a leading firm unleashes endogenous forces targeted at countering a specific impending organizational lock-in.

This study argues that, endogenous forces unleashed by organizations into the industry that disturb the status quo can result in inter-path dependence between the firm and the industry. The industry feeds back onto the organization as external forces and such mutually reinforced mechanisms lead to coevolutionary lock-in between the organization and its industry. Endogenous forces unleashed during the phase of organizational lock-in that leads to coevolutionary lock-in help the firm escape quickly from internal path dependence.

Through higher intensity of R&D efforts, endogenous forces from firms also increase the firm's absorptive capacity that is cumulative and carried through to the subsequent phases. Industry leaders, such as TSMC, have appropriated coevolutionary lock-in to help the organization escape and avoid potential inefficiencies caused by internal path dependencies. Evidence shows that TSMC has been appropriating this strategy to maintain its leading position. Industry followers like UMC have been following the footsteps dictated by TSMC without unleashing any significant endogenous forces into the industry. UMC's firm-level strategies have been very much bounded by its own organizational path dependence. The proposed framework therefore helps shed light on the question of "why do firms differ", despite having a similar experience during their start-up and catch-up process.

6.2.4 Linkages between the Three Analyses

This study has conducted three key analyses. The first analysis on technological transitions provided insights to how technological dimensions in a regime serve as the fundamental basis to the progress of a high-tech manufacturing industry. The changes in the technological dimensions drive firms to make different choices for their organizational boundaries, which also lead to changes in network boundaries as firms seek external linkages that overall provide a feedback loop to the regime. The first analysis has emphasized the role of external linkages in the feedback loop process, of which the IC industry was found to be largely dominated by firms that pursued virtual vertical integration towards the end of 2000s. Since latecomers in the IC industry have to catch up in changing industrial structures as a result of firms' strategies for external linkages (i.e. the feedback loops), the first analysis also leads to the significance of understanding how exactly latecomers should conduct value coordination in their external networks.

Therefore, the second analytical framework goes further by dividing the structural changes found in the first analysis into six stages (dimensions) while taking into account the changes in value coordination. The catch-up process of the latecomers can thus be examined in detail at each stage. The second analytical chapter provided an in-depth analysis to the role of organizational boundaries and external linkages in the catch-up and leapfrogging process of Taiwanese latecomers in the IC industry. It examined the strategies for business model behind the firms' choices for organizational boundaries. It also examined how the latecomer firms acquired resources from different external linkages by extending the existing latecomer resource acquisition framework. The chapter also extended the findings in the first analysis by providing a deeper scrutiny to the role of external linkages to the Taiwanese latecomers in terms of outside-in (indirect) transfer of knowledge and technologies in open innovation context as well as strategic value coordination in networks.

The first and second analyses have therefore emphasized the crucial role of external linkages in latecomers' catching up and leapfrogging. Furthermore, the first analysis emphasized how the change of technological regimes is endogenous to firms' actions while the second analysis suggests that latecomers could rationally strategize their catch-up and leapfrogging paths. This leads to the importance of understanding how strategies of firms interact with external linkages to achieve the desired outcomes, i.e. how exactly could TSMC's endogenous strategies be influential enough to its upstream and downstream firms and led to changes of regime that seem to be in favour of its leapfrogging process? Hence, the third analysis of the thesis examined how the successful firm (i.e. TSMC) achieved the desired result in terms of its managerial process. The analysis showed how firms' endogenous strategies for external linkages could be planned by organizational leaders through revised expectations and vision

constructions, and explained that those strategies are effective when the firms' suppliers and customers are attracted and conformed to those strategies. TSMC's catch-up strategies and leapfrogging via virtual vertical integration in the IC industry became successful when the mutual-reinforcements between the firm's endogenous strategies and its external linkages progressed into coevolutionary lock-ins. The emphasis on external linkages in the first two analyses also indicates the importance of organizational absorptive capacity to assimilate external knowledge and technologies. The third analysis therefore also took into account the aspect by explaining how TSMC's strategies for external linkages have complemented its internal strategies for building its organizational absorptive capacity.

To sum up, this research has examined the catch-up and leapfrogging process of Taiwanese latecomers in the IC industry by considering the changes of technological regimes as the basis that drive firms to strategize for organizational boundaries which create feedback loops to the regime when firms seek external linkages. As analysed in the thesis, strategic external linkages has played a significant role in catch-up and leapfrogging process of Taiwanese foundries as it provides different opportunities for latecomers to seek vertical upgrading and virtual vertical integration, especially in an environment that evolves into an open innovation context among leading firms. However, although these processes are endogenous to firms' strategies, they are only effective when top management in firms are able to pull off the appropriate strategies at the right time so that the endogenous forces receive positive feedbacks from the other firms in networks and progress into high inter-path dependence between the firms. The success story of TSMC's arrival at the technological frontier has not been easily replicated because its catch-up and leapfrogging strategies have taken into account the appropriate resource acquisition and value coordination strategies for its external

linkages, which have led to successful coevolutionary lock-ins in an industry with evolving industrial structures and value systems.

Nevertheless, the catch-up and leapfrogging process of Taiwanese foundries remains very important to draw lessons for other latecomers in high-tech manufacturing industries, especially the IC industry. The first framework provides a useful template to other high-tech manufacturing industries that are driven by the similar technological nature, i.e. the similar technological dimensions. The second analytical framework is also relevant to latecomers in high-tech manufacturing industries, given its strong emphasis on the interface between the OEM latecomers and the advanced MNCs, value chain coordination, as well as the progress into an open innovation context. The third framework is not only relevant to latecomers' catch-up strategies, but also to industry leadership strategies in other high-tech manufacturing industries. This is because the nature of a high-tech manufacturing industry requires the leading firms to deploy strategies that could lead to technological capabilities that are substantial enough to interfere the industry's status quo, resulting in high inter-path dependence between the leading firms and their external linkages as well as coevolutionary lock-ins.

6.3 Theoretical Implications

This research provides some important theoretical implications. The analysis of technological transitions contributes new theoretical insights to how a technological regime is the result of firms' strategies. The examination of latecomer resource acquisition strategies provides implications to the resource-based view, changing value systems, as well as latecomer catch-up theories. Meanwhile, the case study on TSMC contributes to the theory of vision construction, path dependence, organizational absorptive capacity, as well as coevolutionary lock-in of firms and industry.

6.3.1 Technological Transitions

The first analytical framework has advanced the existing theories on technological regime. Each of the identified dimensions affects the different relationships between the downstream and the upstream firms in the industry in different ways, leading to changing driving forces in the industry. Firms respond to these dynamic changes by making strategic decisions for their organizational boundaries accordingly. The changing network boundaries lead to different ways of value chain coordination that promotes different learning opportunities for firms. Firms' coordination of their external linkages over time disturb the industry's status quo and lead to new technological regime under which firms will subsequently revise their strategies for organizational boundaries.

This study has also incorporated the transition process of an industry shifting its characteristics between Schumpeter Mark I and Schumpeter Mark II. Examining the transition process allows us to identify specific dimensions of a technological regime that are appropriate for latecomer firms to strategize for catching up in a Schumpeter Mark I environment. Under a Schumpeter Mark II environment, greater economies of scale, lower technological opportunities and higher technological appropriability provide a promising environment for latecomers - who have successfully caught up - to strategize and leapfrog the large incumbents in order to become industry leaders.

This study provides a more comprehensive view of the systemic mechanisms between technological regimes and choices of organizational boundaries. It explored the mechanisms of the industry's endogenous transition to a new technological regime, including identifying the critical factors and examining their causal relationships in the transition process. The need for knowledge integration across the downstream and the

upstream firms gave rise to the virtual vertically integrated value chains, of which firms in the industry act as networked modular organizations. It is a flexible organizational system that incorporates the merits of modularity and convergence, which provide new learning gateways for latecomers.

6.3.2 Latecomer Resource Acquisitions

Examining how latecomers catch up in a dynamic industrial structure with changing value systems bring several theoretical implications. Most of the existing literature of resource-based view has sought to address the changing perspective of organizational core-competency in large MNCs as a result of open innovation practices. The study modified this by changing the unit of analysis by examining how latecomer firms can source external knowledge under such changing environments.

By incorporating the evolving concepts for organizational core-competency, the study found that repeating the steps of resource acquisition as outlined in Mathew (2002, 2006) is not a sustainable catch-up strategy. This condition will not hold when the industry is transiting to Dimension III in the framework, where open innovation practices is more prominent than closed innovation and when large MNCs begin to form virtual vertically integrated chains with partners in their networked systems.

The study also seeks to characterize virtual vertical integration as an innovative organizational change and business model. Whereas the previous literature has informed us that each value constellation in an open innovation platform has a dominant firm to lead the coordination of value distribution (Normann & Ramirez, 1993; Vanhaverbeke & Cloudt, 2006), the findings in this study show that such a condition does not hold as the IC industry progressed further into Phase II. The findings show that the Taiwanese pure-play foundries do not rely on one single customer that governs the value

distributions. In fact, all the actors in the networked systems are highly interdependent with each other. Collectively, these firms form a value system that shapes virtual vertical integration, which allows them to source external knowledge from each other.

The study shows how Taiwanese latecomer firms have successfully moved from Dimension I to Dimension III(a). Among them, at least TSMC has arrived at Dimension IV(b), where its technological capabilities allow it to form interdependent relationship with its upstream customers. Through the development of virtual vertical integration and the evolving concept of value creating system, the Taiwanese latecomer does not require to undertake OBM in order to qualify itself as a technology frontier leader. Hence, the framework in this study offers an alternative view to latecomer technological catch-up.

The framework in this study also shows how the latecomer firms acquired resources at their point of insertion into the GVC, as a rational and careful strategy to secure a position in the global network of a high-tech industry. To conduct a greater scrutiny of how firms shape their business models to offer values to their networked systems, this study also extends the resource acquisition strategies outlined in Mathews (2002, 2006). In doing so, it provides greater precision in characterizing the latecomer strategies that complement the needs of the vertically integrated incumbents while fulfilling the needs of the specialized customers across different industry phases.

6.3.3 Organizational Capability Building

The organizational path dependence framework is extended to stretch beyond the boundary of organizations by integrating firm- and industry-level analysis. If the industry's feedback on the organization's endogenous forces is positive, the mutually reinforced mechanisms can disturb the status quo and lead to inter-path dependence.

Endogenous forces unleashed during the phase of organizational lock-in that leads to coevolutionary lock-in help the firm break away quickly from the internal (organizational) lock-in.

The second analytical framework in the study introduced the “visionary key” which allows industry leaders to virtually skip the entire organizational lock-in phase. Because the firm is able to generate impact, to shape and dictate the technical progress of the industry, the resulting coevolutionary lock-in opens up new technological opportunities for the firm.

This study also established a new framework to explain the mechanisms of firm-level generative process of endogenous forces and the formation process of coevolutionary lock-in. In previous studies, path dependence emphasizes how history carries through time in the genesis of novelty, but not so much the conceptualization of the actors’ role in the generative process. This study sheds light on a leader’s considerations in the generative process of de-locking from organizational path dependence.

Successful endogenous forces are well-planned strategies appropriated by firm leaders based on their ability to envision how the firm should be in the future by interpreting the external technological opportunities, the firm’s existing knowledge base, and how the two can be synergized. Through higher intensity of R&D, endogenous forces should have also increased the firm’s absorptive capacity that is cumulative and is continued through to the subsequent phases.

Nevertheless, vision reconstruction is needed if an endogenous force does not yield positive feedbacks from the industry that progress into productive outcomes. The frameworks provide an avenue for future studies that enrich the understanding of sources and processes associated with path breaking and path creation opportunities.

6.4 Managerial Implications

Each of the analytical chapters in this thesis also provides implications to managers of latecomer firms operating in a high-tech industry. Specifically, it contributes more to the firm-level knowledge of managers working in the IC industry and seeking to leapfrog the incumbents. The following summarizes managerial implications drawn from each analytical chapter.

6.4.1 Technological Transitions

The technological dimensions that shape the regime of the IC industry is helpful for firm managers to understand how the fundamental nature of technology affects their business relationship with downstream and upstream firms. Managers can better understand how their choices of organizational boundary can lead to changes in the industry, including affecting the network boundary by collaborating with other actors in the industry.

Moreover, firm managers should also comprehend how their competitors or peers would react to the driving forces that change the relationships between downstream and upstream firms. More importantly, they should be aware that the collective choices on network boundary are able to cause impacts and eventually cause changes to the technological regime. The study also explains how managers can plan for catch-up and leapfrogging strategies in a Mark I and Mark II environment respectively. Each of these environments presents different level of competitiveness among the industry players as explained and requires careful strategic plans as the regime transits from time to time.

6.4.2 Latecomer Resource Acquisitions

Latecomer firms that are lagged behind should perceive the practice of virtual vertical integration as a gateway to external knowledge, which is critical for them to move up the value chain and to catch up with frontier technologies. Managers in these firms should strategize their business models to extend their role across the GVC in time. In addition, the managers should be aware of the changing factors taking place in the industry, including the evolving industrial structure, changing value systems, the role of organizational core competency, and the different interfaces between themselves and the incumbents or advanced MNCs.

6.4.3 Organizational Capability Building

The study shows how entrepreneurs can lead a firm to escape from organizational lock-in that brings inefficiencies to the firm. It also emphasized the role of entrepreneurs in directing a firm to catch up with technology and to lead the industry by making decisions that disturb the industry's status quo. Such a strategy allows the firm and the industry to co-evolve and when inter-path dependence is formed, the firm is able to control its external environment via coevolutionary lock-in.

Organizational leaders can build a firm's knowledge base, hence absorptive capacity, via their visionary strategies and unleashing endogenous forces. This study also shows how vision construction and revised expectations on R&D by firm leaders can eventually bring new technological opportunities to their firms.

6.5 Policy Implications

The formulation of industrial policies has to pay close attention to the issues raised in this study. Institutional support and regulatory framework will not be effective without

taking into account industrial complexities, such as the evolution of technological regime, the dynamic organizational and network boundaries, the changing value systems, and the interpath-dependent mechanisms between firms and industry. The study also provides a framework of how latecomer firms can catch up and leapfrog the incumbents in different value systems, which can be a reference to policy makers charting the roadmap for industrial catch-up.

6.5.1 Technological Transitions

The analytical framework used to examine the transitions of technological regime can help policy makers in latecomer countries understand the mechanisms of the complex technological system of a high-tech manufacturing industry. Moreover, understanding the technological regime of an industry helps policy makers to decide the kinds of innovative activities or R&D that most requires incentives from government including research grants, technical trainings and technology licensing. Furthermore, knowing the direct and indirect impacts of different technological dimensions in a regime to the industrial driving forces - hence the different choices of organizational and network boundaries - can help policy makers to identify effectively which technological dimension to be interfered to achieve certain desired results.

Understanding the relationships between the downstream and the upstream firms and the industry's innovation patterns also help policy makers to identify strategic industry segments to be targeted for the country's technology roadmap and subsequently, to identify the types of business models to be promoted in the country. Furthermore, policy makers from latecomer countries should strategically encourage the indigenous firms to seek the VVI system model as a gateway to leverage on the knowledge from more advanced MNCs. In addition, understanding the value chain coordination of the

industry helps policy makers from latecomer countries to strategize how the indigenous firms can be “inserted” into the existing system and be able to move up the technological value chain.

6.5.2 Latecomer Resource Acquisitions

Despite that the Malaysian government tried to mimic the Taiwan catch-up model, unlike their Taiwanese counterparts, the Malaysian foundries have failed to catch up with the world frontier. The Malaysian government initiated Silterra as part of their technological upgrading efforts. However, the firm entered the industry at a less advantageous timing and the positioning of the firm did not allow it to catch up smoothly. This suggests that institutional support has to be strategic and policy makers should take into consideration the issues discussed in the chapter, especially about the evolving industrial structure, the changing value systems, and the catch-up strategies across different dimensions.

As discussed, the Malaysian foundry was mainly driven by the growth of communication tools; the growing demand for cellular phones in early 2000s; the scarce capacity of wafer fabrication worldwide; and the benefits that foundry can bring to fabless companies and advantages of a ‘pure-play foundry’ over the IDM model. However, evidence shows that having initial knowledge towards these areas does not guarantee success given the ever-changing forces in the industry.

Industrial policies targeting to catch up in a high-tech industry like the IC industry should seek to promote the types of technology based on the criteria set out and take into account the influencing factors identified in this study. To create values to customers and suppliers within individual networked systems, the important criteria for the types of technologies to be leveraged or built include rareness, imitability,

transferability, competitiveness and substitutability. The technology roadmap for national catch-up should be insured with a back-up plan like how the Taiwanese government strategized. Policy makers should also formulate industrial policies based on strategic choices in business model and production specialization.

6.5.3 Organizational Capability Building

This study shows that certain strong interpath-dependence between firms and the industry can lead to coevolutionary lock-in, which is capable of altering the direction of the industry's progress. If the policy makers have a clearly defined catch-up roadmap, they can promote stronger interdependent linkages among the relevant actors in the industry through various kinds of incentives to induce the progress of the plans.

The organizational study on TSMC has showcased the potential influence of mutual reinforcement between firms and external parties. In fact, while designing the catch-up roadmap, government can formulate policies that enhance mutual reinforcement between relevant actors in targeted industries to induce a more effective progress. Moreover, given that the development of organizational absorptive capacity is a path-dependent process, policy makers need to promote incentives that help firms to source for external knowledge that deepen the firm's existing internal knowledge. Industrial policies that promote the linkages among the relevant firms that complement the knowledge of each other should gain further attention.

6.6 Limitations and Future Direction of Research

Since the first analytical framework was drawn specifically for the evolutionary IC industry, the analysis cannot be easily generalized for other industries because technological learning involves differing degrees of specificity, tacitness, complexity

and independence and vary across different nature of technologies (Winter, 1987). In other industries, different dimensions of technological regime may have more prominent roles in determining organizational boundaries. However, if the analysis is applied to other high-tech manufacturing industries, most of the identified technological dimensions in this analysis remain relevant as the industries are most likely driven by similar technological nature. This also means that, for each of the same technological dimensions, the responding driving forces and choices of organizational and network boundaries could behave in similar patterns in the other high-tech manufacturing industries. By identifying the exact sets of technological dimensions for other high-tech manufacturing industries in the future would certainly provide more precision to the understanding of technological transitions in those industries, while improving the generalizability of this study.

In addition, because the focus of the first analytical chapter is to examine how the transitions of the regime are contingent upon the actions of firms in a high-tech manufacturing industry, the analysis is done under the condition that the processes take place in a static institutional environment with no path-breaking institutional forces aimed at interfering the industry's status quo. With that condition, the study has not explored the potential role of institutions in supporting firms to catch up with or leapfrog incumbents by altering the degrees of the technological dimensions. Nevertheless, in the event that such external forces exist, the chapter's arguments on the relationships between the degrees of the technological dimensions, the industrial driving forces, as well as the choices of organizational and network boundaries would still be relevant. For instance, if a government provides high incentives and financial supports to its latecomer OEM firms to shorten their time to migrate to more efficient and higher manufacturing capacity, it leads to higher influence of economies of scale in the

industry. However, a higher manufacturing gap between vertically integrated firms and the OEM firms would still lead to more outsourcing practices by the vertically integrated firms and higher growth of the OEMs. Although not all of the changes in the technological dimensions might be endogenous to firms (as a result of the feedback loops) in that case, the proposed framework still remains as a useful template to understand technological systems and transitions, driving forces and relationships between upstream and downstream firms, as well as dynamics of organizational boundaries and the resultant network boundaries of a high-tech manufacturing industry.

The second analytical framework offers a parsimonious way to distinguish the phases, given the evolution of the industrial structure is an on-going process. The increasingly blurred boundaries of organizations make it difficult to clearly craft the moments when the processes should begin or end. Besides, this study did not attempt to theorize open innovation, as pursued by many existing studies. Instead, to explain the catch-up phenomenon, this study uses the concept to discuss the issue of changing value systems and bridges the concept to the notion of an emerging industrial structure, i.e. virtual vertical integration. Hence, it calls for future research to provide a more profound scrutiny in order to enhance the understanding of the issues, which are most likely also faced by other high-tech manufacturing industries.

The extended frameworks for path dependence can be useful for the understanding of organizational theories and industrial dynamics of high-tech manufacturing industries, especially the IC industry. Nevertheless, to simplify the research, the industry analysis is bounded as the research only incorporates positive feedbacks from the industry that respond to the firm's specific endogenous forces. The research also emphasizes the potential of coevolutionary lock-in in helping firms escape from organizational path dependence, rather than exploring the potential inertia arising from such lock-in. It will

be useful to incorporate this scope in future studies. The frameworks also provide an avenue for more future studies that enrich the understanding of sources and processes associated with the emergence of path breaking opportunities.

References

- Abramovitz, M. (1956). Resource and output trends in the United States since 1870. *American Economic Review*, 46, 5-23.
- Afuah, A. (2004). *Business models: A strategic management approach*. New York: McGraw-Hill.
- Akamatsu, K. (1962). A historical pattern of economic growth in developing countries. *The Developing Economies*, 1(1), 3-25.
- Amann, E., & Cantwell, J. (2012). *Innovative firms in emerging market countries*. Oxford: Oxford University Press.
- Amsden, A. (1989). *Asia's next giant: South Korea and late industrialization*. Oxford University Press, New York.
- Antonelli, C. (2008). Pecuniary knowledge externalities: The convergence of directed techno-logical change and the emergence of innovation systems. *Industrial and Corporate Change*, 17(5), 1049–1070.
- Arora, A., & Gambardella, A. (1994). Evaluating technological information and utilizing it: Scientific knowledge, technological capability and external linkages in biotechnology, *Journal of Economics and Behaviour organization*, 38, 361-379.
- Arthur, W. B. (1989). Competing technologies, increasing returns, and lock-in by historical events. *Economic Journal*, 99, 116–131.
- Arthur, W. B. (1994). *Increasing returns and path dependence in the economy*. Ann Arbor: University of Michigan Press.
- Audretsch, D. B. (1995). *Innovation and industry evolution*. Cambridge, MA: The Massachusetts Institute of Technology (MIT) Press.
- ASML. (2012). *Corporate history*. Retrieved 17, December, 2012, from <http://www.asml.com/asml/show.do?lang=EN&ctx=33254>
- Barney, J. B. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17, 99–120.

- Bassanini, A.P., & Dosi, G. (2001). When and how chance and human will can twist the arms of Clio: An essay on path dependence in a world of irreversibilities. In R. Garud & P. Karnøe (Eds.), *Path dependence and creation* (pp. 41-68). London: Lawrence Erlbaum.
- Bierly, P., & Chakrabarti, A. (1996). Generic knowledge strategies in the U.S. pharmaceutical industry. *Strategic Management Journal*, 17, (winter special issue), 123-135.
- Blomstrom, M., & Kokko, A. (2001). Foreign direct investment and spillovers of technology. *International Journal of Technology Management*, 22(5/6), 435-454.
- Brandenburger, A., & Nalebuff, B. (1996). *Co-opetition*. New York: Broadway Business.
- Brandenburger, A., & Stuart, H. (1996). Value-based business strategy. *Journal of Economics and Management Strategy*, 5, 5-24.
- Breschi, S., Malerba, F., & Orsenigo, L. (2000). Technological regimes and Shumpeterian patterns of innovation. *Economic Journal*, 110(463), 388-410.
- Brown, C., & Linden, G. (2009). *Chips and change: How crisis reshapes the semiconductor industry*. Cambridge: The Massachusetts Institute of Technology (MIT) Press.
- Brusoni, S., Prencipe, A., & Pavitt, K. (2001). Knowledge specialization, organizational coupling and the boundaries of the firm: Why firms know more than they make? *Administrative Science Quarterly*, 46(4): 597-621.
- Buchanan, A. (1995). Privatization and just healthcare. *Bioethics*, 9(3), 220-239.
- Burgelman, R. A. (1994). Fading memories: A process theory of strategic business exit in dynamic environments. *Administrative Science Quarterly*, 39, 24-56.
- Burgelman, R. A. (2002). Strategy as vector and the inertia of coevolutionary lock-in. *Administrative Science Quarterly*, 47, 325-357.
- Burgelman, R. A. (1996). A process model of strategic business exit: Implications for an evolutionary perspective on strategy. *Strategic Management Journal*, 17, 193-214.

- Burgelman, R. A., & Grove, A. S. (1996). Strategic dissonance. *California Management Review*, 38(2), 8–25.
- Burgelman, R. A., & Grove, A.S. (2007). Let chaos reign, then rein in chaos repeatedly: Managing strategic dynamics for corporate longevity. *Strategic Management Journal*, 28, 965–978.
- Callon, M. (1986). The sociology of an actor-network: The case of the electric vehicle. In M. Callon & R. Law (Eds.), *Mapping the dynamics of science and technology: Sociology of science in the real world* (pp. 19-34). London: MacMillan.
- Cantwell, J. (2013). Blurred boundaries between firms, and new boundaries within (large multinational) firms: The impact of decentralized networks for innovation. *Seoul Journal of Economics*, 26(1): 1-32.
- Castaldi, C., & Dosi, G. (2006). The grip of history and the scope for novelty: Some results and open questions on path dependence. In A. Wimmerand & R. Koessler (Eds.), *Understanding Change Models, Methodologies and Metaphors*. London: Palgrave.
- Cassiman, B., & Veugelers, R. (2002). R&D cooperation and spillovers: Some empirical evidence from Belgium. *American Economic Review*, 92 (4), 1169-1184.
- Chang, M. (2007). Foundry future: Challenges in the 21st century. IEEE International Solid-State Circuits Conference, *Digest of Technical Papers*, 18-23.
- Chesbrough, H., & Rosenbloom, R.S. (2002). The role of the business model in capturing value from innovation: Evidence from Xerox corporation's technology spin-off companies. *Industrial and Corporate Change*, 11(3), 529-555.
- Chesbrough, H. (2003). *Open innovation: The new imperative for creating and profiting from technology*. Boston: Harvard Business School Press.
- Chesbrough, H. (2006). *Open innovation business models: How to thrive in the new innovation landscape*. Boston: Harvard Business School Press.
- Chesbrough, H., Vanhaverbeke, W., & West, J. (Eds). (2006). *Open innovation: Researching a new paradigm*. Oxford: Oxford University Press.

- Christensen, J-F. (2006). Wither core competency for the large corporation in an open innovation world? In H. Chesbrough, W. Vanhaverbeke & J. West (Eds.), *Open innovation: Researching a new paradigm* (pp. 35-61). Oxford: Oxford University Press.
- CLSA Emerging Markets. (2005). Available through: CLSA Asia-Pacific Markets research database.
- CLSA Research. (2012). Available through: CLSA Asia-Pacific Markets research database, 1998 - 2012.
- CNSE - College for Nanoscale and Science Engineering. (2012). *CNSE's Albany NanoTech Complex*. Retrieved 30, April, 2013, from <http://cnse.albany.edu/WorldClassResources/CNSEAlbanyNanoTechComplex.aspx>
- Cohen, W. M., & Levin, R. C. (1989). Empirical studies of innovation and market structure. In R. Schmalensee & R. Willig (Eds.), *Handbook of industrial organization* (pp. 1061-1249). New York: Elsevier Science Publishers.
- Cohen, W., Levinthal, D., 1990. Absorptive capacity: A new perspective on learning and innovation, *Administrative Science Quarterly*, 35 (1), 128-52.
- Collier, R. B., & Collier, D. (1991). *Shaping the political arena: Critical junctures, the labor movement, and regime dynamics in Latin America*. Princeton, NJ: Princeton University Press.
- Common Platform. (2013). *About us*. Retrieved 16, April, 2012, from <http://www.commonplatform.com/about/>
- Conner, K., & Prahalad, C. K. (1996). A resource-based theory of the firm: Knowledge versus opportunism. *Organization Science*, 7, 477-501.
- Coriat, B., & Dosi, G. (1998). Learning how to govern and learning how to solve problems: On the coevolution of competences, conflicts and organizational routines. In A. D. Chandler, Jr. P. Hagström, and Ö. Sölvell (Eds.), *The dynamic firm: The role of technology, strategy, organization, and regions* (pp. 103-133). Oxford: Oxford University Press.
- Credit Suisse. (2012). *Asian semiconductors*. Research report, Credit Suisse, October 2011.

- Credit Suisse. (2013). Available through: Foundry model research database.
- Dahlander, L., & Gann, D.M. (2010). How open is innovation? *Research Policy*, 39, 699-709.
- Dasgupta, P., & Stiglitz, J. (1980). Industrial structure and the nature of innovative activity. *Economic Journal*, 90, 266-293.
- David, P. A. (1985). Clio and the economics of QWERTY. *American Economic Review*, 75, 332-337
- David, P. A. (1994). Why are institutions the “carriers of history”? Path dependence and the evolution of conventions, organizations and institutions. *Structural Change and Economic Dynamics*, 5, 205-220.
- David, P. A. (2001). Path dependence, its critics and the quest for 'historical economics'. In P. Garrouste & S. Ioannides (Eds.), *Evolution and Path Dependence in Economic Ideas: Past and Present* (pp. 15-40). Cheltenham, UK: Edward Elgar.
- Dolata, U. (2009). Technological innovations and sectoral change. Transformative capacity, adaptability, patterns of change: An analytical framework. *Research Policy*, 38(6), 1066–1076.
- Doyle, L. (2003). Synthesis through meta-ethnography: Paradoxes, enhancements, and possibilities. *Qualitative Research*, 3(3), 321-344.
- Dosi, G. (1982). Technological paradigms and technological trajectories. *Research Policy*, 11, 147-162.
- Dosi, G., Nelson, R., & Winter, S. (2000). *The nature and dynamics of organizational capabilities*. New York: Oxford University Press.
- Dosi, G., Marengo, L., Paraskevopoulou, E., & Valente, M. (2011). *The value and dangers of remembrance in changing worlds: A model of cognitive and operational memory of organizations*. Pisa: Sant’ Anna School of Advanced Studies. LEM Working Paper.
- Dobusch, L., & Schüßler, E. (2012). Theorizing path dependence: A review of positive feedback mechanisms in technology markets, regional clusters, and organizations. *Industrial and Corporate Change*, 22 (3), 617-647.

- Dubash, M. (2005, April 13). Moore's Law is dead, says Gordon Moore. *Techworld*. Retrieved 6, June, 2013, from <http://news.techworld.com/operating-systems/3477/moores-law-is-dead-says-gordon-moore/>
- Dyer, J. H. (1997). Effective interfirm collaboration: How firms minimize transaction costs and maximize transaction value. *Strategic Management Journal*, 18(7), 535–556.
- Dyer, J. H., & Singh, H. (1998). The relational view: Cooperative strategy and sources of interorganizational competitive advantage. *Academy of Management Review*, 23(4), 660-679.
- Edquist, C., & Jacobssen, S. (1987). The integrated circuit industries in India and South Korea in an international techno-economic context. *Industry and Development*, 21: 1-62.
- Frankel, M. (1955). Obsolence and technological change in a maturing economy. *American Economic Review*, 45, 296-319.
- Fransman, M. (1994). Information, knowledge, vision and theories of the firm. *Industrial and Corporate Change*, 3(3), 713-757.
- Fransman, M. (1999). *Visions of innovation: The firm and Japan*. New York: Oxford University Press.
- Gartner. (2012, March 30). Gartner says semiconductor foundry market grew 5.1 percent in 2011 to reach \$29.8 billion. *Gartner*. Retrieved 15, June, 2013, from <http://www.gartner.com/it/page.jsp?id=1970115>
- Gartner. (2013). *Fab database: Worldwide, fourth quarter 2011 update*. Gartner Research.
- Garud R., & Karnøe, P. (Eds.). (2001). *Path dependence and creation*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Gassmann, O., & Enkel, E. (2004). Towards a theory of open innovation: Three core process achetypes. Proceedings of the *R&D Management Conference (6th)*, Lisbon, Portugal, July 6-9.
- Gerschenkron, A. (1952). Economic backwardness in historical perspective. In B. F. Hoselitz (Ed.). *The progress of underdeveloped areas* (pp. 3-29). Chicago: University of Chicago Press.

- Gerschenkron, A. (1962). *Economic backwardness in historical perspective. A Book of Essays*. Cambridge: Harvard University Press.
- Gläser, J., & Laudel, G. (2013). Life with and without coding: Two methods for early-stage data analysis in qualitative research aiming at causal explanations. *Forum: Qualitative Social Research*, 14(2), Art. 5.
- Granstrand, O., Patel, P., & Pavitt, K. (1997). Multi-technology corporations: Why they have distributed rather than distinctive core competences. *California Management Review*, 39, 8-25.
- Gruber, M. (2010). Exploring the origins of organizational paths: Empirical evidence from newly founded firms. *Journal of Management*, 36(5), 1143–1167.
- Gomes-Casseres, B. (2003). Competitive advantage in alliance constellations. *Strategic Organization*, 1(3), 327-335.
- Gort, M., & Klepper, S. (1982). Time paths in the diffusion of product innovations. *Economic Journal*, 92, (September), 630-653.
- Grant, R. M. (1996) Toward a knowledge-based theory of the firm. *Strategic Management Journal*, 17 (winter special issue), 109-122.
- Hagedoorn, J., (1993) Understanding the rationale of strategic technology partnering: Inter-organizational modes of cooperation and sectoral differences. *Strategic Management Journal*, 14, 371–385.
- Hampden-Turner, C. (1990). *Charting the corporate mind*. New York: Free Press.
- Hobday, M. (1995). *Innovation in East Asia: The challenge to Japan*. Hants: Edward Elgar.
- IC Insights. (2012). Available through: Semiconductor Market Research database.
- IC Insights. (2014). *The McClean Report*, 2014 edition. Arizona USA:IC Insights.
- ITIS – Industrial Technology Information Services. (1999). *Semiconductor industry yearbook 1999*. Taiwan: Economic Department, Industrial Technology Research Institute (ITRI).

- IMEC. (2012). Implementing the “R” in R&D. Retrieved 17, December, 2012, from <http://annualreport.imec.be/How-can-we-help-/Worldwide-R-D-provider/page.aspx/1227>
- Kamien, M. I., & Schwartz, N. L. (1982). *Market structure and innovation*. Cambridge: Cambridge University Press.
- Kim, C. W., & Lee, K. (2003). Innovation, technological regimes and organizational selection in industry evolution: A ‘history friendly model’ of the DRAM industry. *Industrial and Corporate Change*, 12(6), 1195-1221.
- Kim, L. (1997). *From imitation to innovation*. Cambridge: Harvard Business School Press.
- Kim, L. (1998). Crisis construction and organizational learning: Capability building in catching-up at Hyundai Motor. *Organization Science*, 9(4), 506-521.
- Koch, J. (2011). Inscribed strategies: Exploring the organizational nature of strategic lock-in. *Organization Studies*, 32, 337–363.
- Kodama, M. (2011). *Interactive business communities: Accelerating corporate innovation through boundary networks*. Surrey: Gower Publishing Limited.
- Kogut, B., & Zander, U. (1992). Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science*, 3, 383-397.
- Lamberg, J. A., & Tikkanen, H. (2006). Changing sources of competitive advantage: Cognition and path dependence in the Finnish retail industry 1945-1995. *Industrial and Corporate Change*, 15(5), 811–846.
- Langlois, R. N. (2003). The vanishing hand: The changing dynamics of industrial capitalism. *Industrial and Corporate Change*, 12(2): 351-385.
- Latour, B. (1987). *Science in action: How to follow engineers and scientists through society*. Cambridge, Mass.: Harvard University Press.
- Law, J. (1992). Notes on the theory of the actor-network: Ordering, strategy, and heterogeneity. *Systems Practice*, 5 (4), 379-393.
- Lee, K., & Lim, C. S. (2001). Technological regimes, catching-up and leapfrogging: Findings from the Korean industries. *Research Policy*, 30, 459-483.

- Levin, R. C., Klevorick, A. K., Nelson, R. R., & Winter, S. G. (1987). Appropriating the returns from industrial research and development. *Brookings Papers on Economic Activity*, 3, 783-820.
- Levin, R. C. and Reiss, P. C., 1988. Cost-reducing and demand creating R&D with spillovers. *Rand Journal of Economics*, 19 (4), 538-556.
- Lu, N. C. C. (2005, June). Emerging era for heterogeneous integration for system chips: Technology and business solutions. *Fabless Semiconductor Association (FSA)*, 12(2).
- Lundvall, B. A. (Ed.). (1992). *National systems of innovation. Towards a theory of innovation and interactive learning*. London: Pinter Publishers.
- Madhavan, R., Koka, B. R., & Prescott, J. E. (1998). Networks in transition: How industry events (re)shape interfirm relationships. *Strategic Management Journal*, 19, 439–459.
- Malerba, F., & Orsenigo, L. (1994). Schumpeterian patterns of innovation. *Cambridge Journal of Economics*, 19(1), 47-66.
- Malerba, F., & Orsenigo, L. (1996). Schumpeterian patterns of innovation are technology specific. *Research Policy*, 25(3), 451-478.
- Malerba, F. (2007). Innovation and the dynamics and evolution of industries: Progress and challenges. *International Journal of Industrial Organization*, 25, 675-699.
- Malerba, F., Nelson, R., Orsenigo, L., & Winter, S. (2008). Vertical integration and disintegration of computer firms: A history friendly model of the co-evolution of the computer and semiconductor industries. *Industrial and Corporate Change*, 17(2), 197-231.
- Malerba, F., & Nelson, R. (2012). *Economic development as a learning process: Differences across sectoral systems*. Cheltenham: Edward Elgar.
- Manning, S., & Sydow, J. (2011). Projects, paths, and practices: Sustaining and leveraging project-based relationships. *Industrial and Corporate Change*, 20(5), 1369–1402.
- Mathews, J. (1997). A Silicon Valley of the East: Creating Taiwan's semiconductor industry. *California Management Review*, 39, 26-54.

- Mathews, J., & Cho, D. S. (2000). *Tiger technology: The creation of a semiconductor industry in East Asia*. Cambridge: Cambridge University Press.
- Mathews, J. (2002). Competitive advantages of the latecomer firm: A resource-based account of industrial catch-up strategies. *Asia Pacific Journal of Management*, 19, 467-488.
- Mathews, J. (2006). Catch-up strategies and the latecomer effect in industrial development. *New Political Economy*, 11(3), 313-335.
- NEAC - National Economic Advisory Council. (2010). *New economic model for Malaysia part 1*. Kuala Lumpur: National Economic Advisory Council.
- Nelson, R., & Winter, S. (1982). *An evolutionary theory of economic change*. Cambridge Mass.: Harvard University Press.
- Nelson, R., & Winter, S. (1977). In search of a useful theory of innovations. *Research Policy*, 6(1), 36-76.
- Nelson, R. (1991). Why do firms differ, and how does it matter? *Strategic Management Journal*, 12 (Special issue: Fundamental research issues in strategy and economics), 61-74.
- Nelson, R. (2008). Economic development from the perspective of evolutionary economic theory. *Oxford Development Studies*, 36(1), 9-21.
- Noblit, G. W., & Hare, R.D. (1988). *Meta-ethnography: Synthesizing qualitative studies*. Newbury Park, CA: Sage Publications.
- Nonaka, I. (1991). The knowledge creating company. *Harvard Business Review*, 69, 96-104.
- Normann, R., & Ramirez, R. (1993). From value chain to value network: Designing interactive strategy. *Harvard Business Review*, 71(4), 65-77.
- North, D. C. (1990). *Institutions, institutional change, and economic performance*. Cambridge: Cambridge University Press.
- Park, T. Y., Choung, J. Y., & Min, H. G. (2008). The cross-industry spillover of technological capability: Korea's DRAM and TFT-LCD industries. *World Development*, 36(12), 2855-2873.

- Patel, P., & Pavitt, K. (1997). The technological competencies of the world's largest firms: Complex and path-dependent, but not much variety. *Research Policy*, 26, 141-156.
- Pavitt, K. (1986). Technology, innovation and strategic management. In J. McGhee & H. Thomas (Eds.), *Strategic Management Research*. New York: Wiley.
- Pavitt, K. (1998). Technologies, products and organization in the innovating firm: What Adam Smith tells us and Joseph Schumpeter doesn't. *Industrial and Corporate Change*, 7, 433-51.
- Piore, M., & Sabel, C. (1984). *The second industrial divide*. New York: Basic Books.
- Penrose, E. (1959). *The theory of the growth of the firm*. New York: Oxford University Press.
- Perez, C., & Soete, L. (1988). Catching up in technology: Entry barriers and windows of opportunity. In G. Dosi, C. Freeman, R. Nelson, G. Silverberg & L. Soete (Eds.), *Technical Change and Economic Theory* (pp. 458-479). London: Pinter.
- Pfeffer, J., & Salancik, G. R. (1978). *The external control of organizations*. New York: Harper & Row.
- Porter, M. (1985). *Competitive advantage: Creating and sustaining superior performance*. New York: Free Press.
- Porter, M. (1990). *The competitive advantage of nations*. New York: Free Press.
- Porter, M. (1996). What is strategy? *Harvard Business Review*, November-December, 61-78.
- Powell, W., Koput, K., & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of control of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly*, 41, 116-145.
- Prahalad, C. K., & Hamel, G. (1990). The core competence of the corporation. *Harvard Business Review*, 68(3), 79 – 91.
- Ramirez, R. (1999). Value co-production: Intellectual origins and implications for practice and research. *Strategic Management Journal*, 20(1), 49-65.

- Rasiah, R. (1988). Production in transition within the semiconductor industry and its impact on Penang. *Kajian Malaysia*, VI (June), 85-111.
- Rasiah, R. (2010). Are electronics firms in Malaysia catching up in the technology ladder? *Journal of Asia Pacific Economy*, 15(3), 301-319.
- Rasiah, R. (2011). The role of institutions and linkages in learning and innovation. *International Journal of Institutions and Economies*, 3(2), 165-172.
- Rasiah, R., Kong, X. X., Lin, Y., & Song, J. (2012). Variations in the catch up experience in the semiconductor industry in China, Korea, Malaysia and Taiwan. In F. Malerba & R. Nelson (Eds.), *Economic development as a learning process: Differences across sectoral systems*. Cheltenham: Edward Elgar.
- Rasiah, R., & Lin, Y. (2005). Learning and innovation: The role of market, government and trust in the information hardware industry in Taiwan. *International Journal of Technology and Globalisation*, 1(3), 400-432.
- Richardson, G. B. (1990). *Information and investment*. Oxford: Oxford University Press.
- Rose, R. (1991). Comparing forms of comparative analysis. *Political Studies*, XXXIX, 446-462.
- Rosenberg, N. (1982). *Inside the black box: Technology and economics*. Cambridge: Cambridge University Press.
- Rosenberg, N. (1990). Why do firms do basic research (with their own money)? *Research Policy*, 19, 165-174.
- Rothwell, R. (1994). Towards the fifth-generation innovation process. *International Marketing Review*, 11(1), 7-31.
- Rostow, W. W. (1960). *The stages of economic growth: A non-communist manifesto*. Cambridge: Cambridge University Press.
- Rothwell, R., Freeman, C., Horlsey, A., Jervis, V.T.P., Robertson, A.B., & Townsend, J. (1974). SAPPHO updated - project SAPPHO phase II. *Research Policy*, 3(3), 258-291.
- Saito, M. (2009). Global semiconductor industry trend - IDM versus foundry approaches. *Proceedings of the IEEE*, 97(10), 1658-1660.

- Sanchez, R., & Heene, A. (1997). Reinventing strategic management: New theory and practice for competence-based competition. *European Management Journal*, 15(3), 303–317.
- Saxenian, A. (1994). *Regional advantage. Culture and competition in Silicon Valley and Route 128*. Cambridge: Harvard University Press.
- Schumpeter, J. A. (1934). *The theory of economic development*. Cambridge Mass.: Harvard Economic Studies.
- Schumpeter, J. A. (1939). *Business cycles: A theoretical, historical, and statistical analysis of the capitalist process*. New York: McGraw-Hill.
- Schumpeter, J. A. (1942). *Capitalism, socialism and democracy*. London: Allen & Unwin.
- Spender, J. C. (1989). *Industry recipes: The nature and sources of managerial judgment*. Oxford: Blackwell.
- Swann, P., & Gill, J. (1993). *Corporate vision and rapid technological change: The evolution of market structure*. London: Routledge.
- Sydow, J., Schreyong, G., & Koch, J. (2009). Organizational path dependence: Opening the black box. *Academy of Management Review*, 34(4), 689-709.
- Sydow, J., Lerch, F., & Staber, U.H. (2010). Planning for path dependence? The case of a network in the Berlin-Brandenburg optics cluster. *Economic Geography*, 86(2), 173–195.
- Teece, D. J. (1980). Economics of scope and the scope of the enterprise. *Journal of Economic Behavior and Organization*, 1(3), 223-247.
- Teece, D. J. (1984). Economic analysis and strategic management. *California Management Review*, 26(3), 87-110.
- Teece, D. J. (1986). Profiting from technological innovation. *Research Policy*, 15(6), 285-306.
- Teece, D. J. (1988). Technological change and the nature of the firm. In G. Dosi, C. Freeman, R. Nelson, G. Silverberg & L. Soete (Eds.), *Technical Change and Economic Theory* (pp. 256-281). London: Pinter.

- Teece, D., 1996. Firm organization, industrial structure, and technological innovation. *Journal of Economic Behavior & Organization*, 31, 193-224.
- Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, 18, 509–533.
- Tsai, W. (2000). Social capital, strategic relatedness, and the formation of intra-organizational strategic linkages. *Strategic Management Journal*, 21, 925-939.
- UNIDO – United Nations Industrial Development Organization. (2002/2003). *Industrial development report*, Chapter 6.
- USPTO – United States Patent and Trademark Office. (2011). *General patent statistics reports*, Patent Technology Monitoring Team (PTMT). United States: USPTO.
- Torodova, G., & Durisin, B. (2007). Absorptive capacity: Valuing a reconceptualization. *Academy of Management Review*, 32(3), 774–786.
- Vanhaverbeke, W., & Peeters, N. (2005). Embracing innovation as strategy: Corporate venturing, competence building and corporate strategy making. *Creativity and Innovation Management*, 14(3), 246-257.
- Vanhaverbeke, W., Cloudt, M., & Vrande, V.V. (2008). *Connecting absorptive capacity and open innovation*. SSRN Working Paper No. 1091265, February 2008.
- Vanhaverbeke, W., & Cloudt, M. (2006). Open innovation in value networks. In H. Chesbrough, W. Vanhaverbeke & J. West (Eds.), *Open innovation: Researching a new paradigm* (pp. 258-281). Oxford: Oxford University Press.
- Veblen, T. (1915). *Imperial Germany and the industrial revolution*. New York: A. M. Kelley (reprinted in 1964).
- Von Hippel, E. (1988). *The sources of innovation*. New York: Oxford University Press.
- Wernerfelt, B. (1984). A resource-based view of the firm. *Strategic Management Journal*, 5, 171–180.
- Williamson, O. E. (1975). *Markets and hierarchies*. New York: Free Press.
- Williamson, O. E. (1985). *The economic institutions of capitalism: Firms, markets, relational contracting*. New York: Free Press.

- Winter, S. (1984). Shumpeterian competition in alternative technological regimes. *Journal of Economic Behavior & Organization*, 5, 287-320.
- Winter, S. (1987). Knowledge and competence as strategic assets. In D. J. Teece (Ed.), *The competitive challenge: Strategies for industrial innovation and renewal* (pp. 159-184). Cambridge Mass.: Ballinger.
- Yin, R. (1994). *Case study research: Design and methods* (2nd ed.). Beverly Hills, CA: Sage Publishing.
- Yin, R. (2011). *Qualitative research from start to finish*. New York: The Guilford Press.
- Yin, R. (2014). *Case study research: Design and methods* (5th ed.). California: SAGE Publications.
- Yoon, M., & Malerba, F. (2010). *Technological interrelatedness, knowledge generality and economies of scale in the evolution of firm boundaries: A history-friendly model of the fabless ecosystem*. Paper presented at the DRUID Summer Conference, Imperial College London Business School, United Kingdom, June 16-18, 2010.
- Zajac, E. J., & Olsen, C. P. (1993). From transaction cost to transactional value analysis: Implications for the study of interorganizational strategies. *Journal of Management Studies*, 30, 131-145.

SUPPLEMENTARY

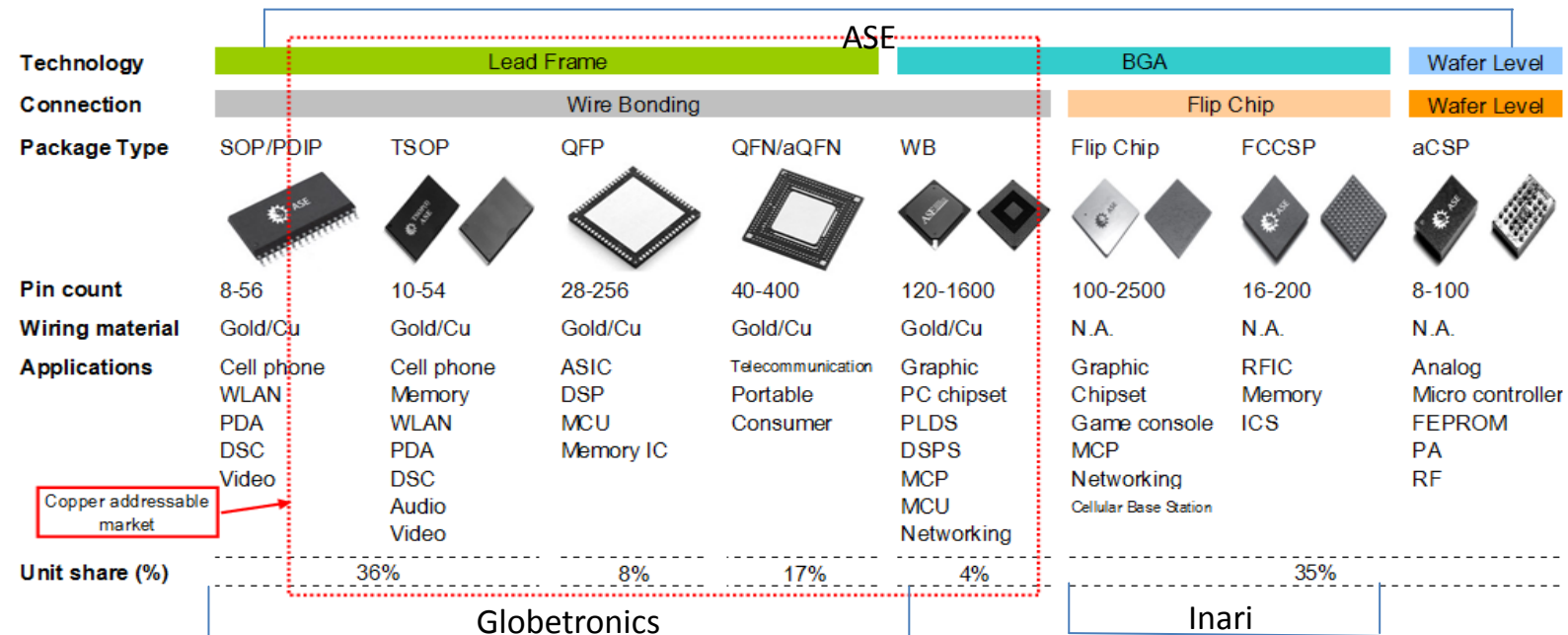
LIST OF PUBLICATIONS AND PAPERS PRESENTED

- Rajah Rasiah and Yap Xiao Shan (2014) “Institutions, technological capabilities and domestic production linkages in the semiconductor industry in Singapore”, *Asia Pacific Business Review*, forthcoming [Accepted].
- Rajah Rasiah and Yap Xiao Shan (2014) “Institutions, regional production linkages and technological capabilities in the semiconductor industry in Malaysia”, *Asia Pacific Business Review*, forthcoming [Accepted].
- Rajah Rasiah, Yap Xiao Shan and VGR Chandran Govindaraju (2014) “Crisis Effects on the Electronics Industry in Southeast Asia”, *Journal of Contemporary Asia*. Published online: June 5, 2014 [DOI: 10.1080/00472336.2014.923637].
- Rajah Rasiah and Yap Xiao Shan (2014) “Regional value chains in ASEAN: The case of automotive, clothing and electronic components”, report prepared for *United Nations Conference on Trade and Development (UNCTAD)*, ASEAN Investment Report 2014 (Chapter 3).
- Wong Chan Yuan and Yap Xiao Shan (2012) “Mapping technological innovations through patent analysis: A case study of foreign multinationals and indigenous firms in China”, *Scientometrics*, 91: pp. 773–787.
- Yap Xiao Shan (2013) “The lost tiger: The technological learning case of Malaysian semiconductor firms”. Presented at the 10th Asian Network for the Economics of Learning, Innovation, and Competence Building Systems (ASIALICS) International Conference 2013, National Graduate Institute for Policy Studies, Tokyo, Japan, September 20-21, 2013.
- Yap Xiao Shan (2013) “Technological regimes, firms’ vertical boundaries, and industry’s innovation patterns: The evolution of the IC industry”. Presented at the 11th Global Network for the Economics of Learning, Innovation, and Competence Building Systems (GLOBELICS) International Conference 2013, Middle East Technical University (METU), Ankara, Turkey, September 11-13, 2013.
- Yap Xiao Shan (2012) “Outplay and outlast: Taiwan Semiconductor Manufacturing Company’s Schumpeterian innovation strategy”. Presented at the 10th Globelics International Conference 2012, Zhejiang Narada Grand Hotel, Hangzhou, China, November 9-11, 2012.

- Yap Xiao Shan and Rajah Rasiah (2012) “Technological trajectory in response to industrial dynamics: The case of the semiconductor industry”. Presented at the 9th ASIALICS International Conference, De La Salle University, Manila, Philippines, October 4-5, 2012.
- Rajah Rasiah and Yap Xiao Shan (2012) “Multinational corporations, global production networks and technological upgrading: Evidence from integrated circuits production firms in Asian developing economies”, Presented at the International Conference on trade, investment and production networks in Asia, Leverhulme Centre for Research on Globalisation and Economic Policy (GEP), University of Nottingham, Chulan Tower, Kuala Lumpur. February 15-16, 2012.
- Yap Xiao Shan (2011) “Can Malaysian firms innovate? A study to reflect the global market position of Malaysian semiconductor firms”, Presented at the 36th Federation of ASEAN Economic Associations (FAEA) Conference, ASEAN after global crisis: Management and change. At CITITEL Hotel, Mid Valley, Kuala Lumpur. November 24-25, 2011.

APPENDIX A

Technology Operations of IC Assembly and Test Firms



Source: ASE, Globetronics, Inari, Gartner.